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ASSESSMENT OF HAZARDOUS WASTE SURFACE IMPOUNDMENT TECHNOLOGY CASE STUDIES AND PERSPECTIVES OF EXPERTS

by

Masood Ghassemi
Michael Haro and Linda Fargo
MEESA
Torrance, California 90504

EPA Contract No. 68-02-3174

Project Officer

Carlton Wiles
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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16. ABSTRACT

The available data were gathered for a large number of case studies of hazardous waste surface impoundments (SI). Actual and projected performances were compared. This collection, analysis and dissemination of the accumulated experience can contribute significantly to improving SI design, construction and operation.

Nine facilities were reviewed and assessed. They represent a range of industries, waste types and volumes, ages, environmental settings, liner types and designs, and systems for leak detection and groundwater monitoring. In addition, nine interviews were held with technical experts in four consulting engineering firms, one waste management company, one liner fabricator/installer, and regulatory agencies in three states. Based on case studies and professional opinions and experiences collected, recommendations for research and development are presented.

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FOREWORD

The environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is the first necessary step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and the solid and hazardous waste pollutant discharges from municipal and community sources; to preserve and treat public drinking water supplies; and to minimize the adverse economic, social, health and aesthetic effects of pollution. This publication is one of the products of that research — a vital communications link between the researcher and the user community.

This document presents case studies in hazardous waste surface impoundment design and operation, as well as professional opinions of technical experts in four leading engineering design firms, one waste management company, one liner fabricator/installer, and regulatory agencies in three states.

Francis T. Mayo, Director
Municipal Environmental Research Laboratory

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ABSTRACT

The available data were gathered for a large number of case studies of hazardous waste surface impoundments (SI). Actual and projected performances were compared. This collection, analysis and dissemination of the accumulated experience can contribute significantly to improving SI design, construction and operation.

Nine facilities were reviewed and assessed. They represent a range of industries, waste types and volumes, ages, environmental settings, liner types and designs, and systems for leak detection and groundwater monitoring. In addition, nine interviews were held with technical experts in four consulting engineering firms, one waste management company, one liner fabricator/installer, and regulatory agencies in three states. Based on case studies and professional opinions and experiences collected, recommendations for research and development are presented.

Poor performance of several ponds was attributed to factors such as lack of good project planning during design and construction phase, failure to execute proper quality assurance and control (QA/QC), deviations from desired liner specifications, inadequate liner-waste compatibility testing, and lack of rigorous site-specific investigations to develop the proper basis for design and construction. Successful performance of SIs at two facilities is attributable to (1) use of a very impermeable clay as liner material after extensive waste-liner permeability studies, (2) use of competent design, construction, and inspection contractors, (3) close scrutiny of all phases of design, construction, and QA inspection by the owner/operator, (4) excellent QA/QC and record-keeping during all phases of the project, and (5) good communication between all parties involved in establishing the SIs.

Technical experts consider the following factors essential to achieving good site performance: siting in good geologic formation; continuity of the geotechnical support throughout the project planning, site investigation, design and construction; construction supervision to ensure adherence to specifications; compaction of clay liner wet of optimum to eliminate air space; consideration of compatibility with waste in selecting liner material; rigorous QA/QC to ensure adequate design and proper liner installation; and provision and maintenance of protective cover for liners.

Areas for research and development include documentation and dissemination of design versus performance data for operating sites, evaluation of waste-liner compatibility under actual conditions, development of reliable techniques for early detection of site failure, establishing criteria for proper design of groundwater monitoring systems with respect to number,

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location and depth of monitoring wells; and studies of causes of and remedies for plugging of leachate collection systems for landfills.

This report was submitted by MEESA in fulfillment of a subcontract with Radian Corporation under the sponsorship of the U.S. Environmental Protection Agency Contract No. 68-02-3174. This report covers the period of September 1983 to May 1984, and the work was completed as of May 1984.

CONTENTS

Foreword iii
Abstract iv
Figures vii
Tables ix
Acknowledgments xii

1. Introduction 1
2. Conclusions and R&D Recommendations 4
    2.1 Lessons from The Case Studies 4
    2.2 Professional Opinions and Experience of Experts . . . 5
    2.3 R&D Recommendations 7
3. Data Collection and Data Base Developmene Methodology 9
    3.1 Case Studies 9
    3.2 Interview with Experts 16
4. Discussion of Case Studies 23
    4.1 General Background Information on the Facilities Covered 23
    4.2 Overview of SI Technology for the Cases Reviewed . . 23
    4.3 Technical Assessments for Individual Sites. 39
5. Overview of the Collected Professional Opinions 46
    5.1 Surface Impoundments Versus Landfills 47
    5.2 Geotechnical and Other Considerations in Siting, Design and Construction 47
    5.3 Liner and Cover Systems Design, Construction and Related Topics 50
    5.4 Leachate Collection System 55
    5.5 Leak Detection and GroundWater Monitoring System . . 55
    5.6 Research and Development Needs 56
    5.7 Regulatory Considerations 59
6. Case Study Reports 61
    Case Study No. 1 61
    Case Study No. 2 75
    Case Study No. 3 79
    Case Study No. 4 97
    Case Study No. 5 115
    Case Study No. 6 137
    Case Study No. 7 155
    Case Study No. 8 178
    Case Study No. 9 185

TYPING GUIDE SHEET
BEGIN FIRST LINE OF HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

7. Interview Reports 203
Interview No. 1. 203
Interview No. 2. 212
Interview No. 3. 216
Interview No. 4. 220
Interview No. 5. 225
Interview No. 6. 229
Interview No. 7. 237
Interview No. 8. 242
Interview No. 9. 249

Appendices

A. Facilities Reviewed but Rejected as Case Studies. 258
B. Miscellaneous Support Data 280

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)

FIGURES

Number Page

1 Facility Layout 62

2 Facility Pond Layout 85

3 Plant Layout 98

4 Layout of Evapoaration/Cooling Ponds 106

5 Leak Detection System Details 107

6 pH of Leakage in Wells Over Time 114

7 Evaporation and Tailings Ponds 116

8 Parameters Affecting Pond Life 119

9 Typical Embankment Design. 125

10 Leak Detection System 127

11 Hydrologic Regimen for Pond 6 Sinkhole Phenomenon 136

12 Layout of Phase I Surface Impoundments 139

13 Site Area Showing Recommended Hydrogeological Improvements 146

14 Location of Monitoring Wells 148

15 Layout of Ponds Showing Damp Soil Areas Discovered . . . . July 1982 (16) 150

16 Trench to Repair Leaks in Pond 8 152

17 Pond 8 Showing Borings at Intersection with Old Stream Channels. 153

18 Plant Pond System Layout 156

19 Schematic of Cooling Pond Exterior Dike Construction 162

Number Page

20 Schematic of Gypsum Pond Side Slopes 164

21 Expansion Gypsum Pond Detail 165

22 Inactive Gypsum Pond Embankment Stages 177

23 Dimensions, Arrangmeent and Flow Pattern for Surface Impoundments 181

24 Plot Plan of Proposed Mine and Mill Facility 187

25 Stream Diversion System 191

26 Cross Section of Embankment 194

27 Intragradient Ladfill Concept 234

28 Conceptual Details of the Hydraulic Barrier Liner 236

29 Plot Plan and Groundwater Wells for Facility A 259

30 Schematics of SI 264

31 Layout of Existing Technologies and Monitoring System. 271

32 Location of Past Treatment/Disposal Practices 272

33 Facility J Pond and Monitoring Locations 276

TABLES

Number Page

1 Facilities Eliminated from Further Consideration in the Preliminary Screening 11

2 Facilities Evaluated but Rejected as Case Study Sites 12

3 Types of Information Sought for the Case Studies 15

4 Typical Letter Requsting Participtaion in and Input to the Program 17

5 Individuals/Organizations Interviewed 19

6 Typical Letter Requesting Review Comments on Draft Interview Reports 22

7 Case Study Facilities - General Features and Waste Charcteristics 24

8 Case Study Facilities - Environmental Features 26

9 Case Study Facilities - Liner and Monitoring Systems 28

10 Basis for Site and Contractor Selection 31

11 Basis for Design and Design Specifications and Costs 33

12 Construction and QA/QC Inspection and Documentation 36

13 Performance and Operating Experience 37

14 Heavy Metals Analysis of Sludge from the "Small" SI 63

15 Analysis of SI Waste 64

16 Analysis of Cooling Ponds Content 65

17 Analyses of Water from Monitoring Wells (MW) and Production Wells (PW) 71

Number Page

18 Statistical Parameters of GroundWater Quality Data in the Vicinity of the Facility 73

19 1982 Groundwater Monitoring Data 90

20 Statistical Analysis of Groundwater Monitoring Data for 1982 . . . 93

21 1978 Leachate Composition 94

22 Spill Analysis 95

23 Gypsum Ponds Test Well Analytical Results 110

24 Analytical Results of Soil Cores Taken Around the Gypsum Ponds . . 111

25 Foundation and Embankment Construction Procedures 123

26 Arsenic concentration Ranges in Well 11/8-22LI (mg/l) 133

27 Typical Geothermal Brine Composition 141

28 Wastes Disposed in Pond 8 in 1981 141

29 Metal Analysis of Pond 8 Waste in mg/l 142

30 Constitutents Found in Three Separate Smaples of Waste from Pond 8 in ppb 142

31 Basic Government Requirements for Establishment of Case Study 6 Hazardous Waste Site 144

32 Analysis of Gypsum Slurry and Cooling Pond Water 158

33 Observation Well Data 169

34 Water Quality Data for Well No. 8 171

35 Monitoring Data for New Wells 172

36 Behavior of Inactive Gypsum Embankments 175

37 Partial Effluent Analysis (mg/l) 182

38 Physical and Chemical Parameters Measured for the Groundwater and Tailings Pond 196

39 Summary of Construction Standards for Waste Management Units . . . 252

40 Estimated Quantities of Wastes Handled at Facility J 274

41 Groundwater Monitoring Quarterly Report 277

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This document presents case studies in surface impoundment design and operation, as well as professional opinions of several leading engineering design firms and the technical staff at three state regulatory agencies. Since the identity of the specific sites covered in the case studies was of little consequence to the goals and objectives of the program, these sites have been kept anonymous in this report. However, MEESA, wishes to express its deepest gratitude to the site owners and operators and to cognizant state agencies who provided data on individual sites and reviewed the draft case study reports. Similarly, we are grateful to the individuals and organizations listed in Table 5 who fully cooperated with the study by providing expert opinions and sharing their experience with the project through interviews and reviews the draft interview reports.

SECTION 1

INTRODUCTION

The Solid and Hazardous Waste Research Division (SHWRD) of EPA's Municipal Environmental Research Laboratory (MERL, Cincinnati, OH) is investigating the use of surface impoundments (SIs) for hazardous waste management. The primary aims of this research are to develop criteria for improved SI design and operation and to provide technical support to EPA's Office of Solid Waste in developing SI regulations according to the provisions of the Resource Conservation and Recovery Act (RCRA).

Currently, the principal source of EPA information on hazardous waste surface impoundments is the Surface Impoundment Assessment (SIA) data base developed by the Office of Drinking Water. Though the data base contains some background survey information on the numbers, types, and uses of wastes handled by municipal, industrial, and agricultural SIs in the United States, it contains little or no information on their engineering design and actual performance. Comparison of projected and actual performances at operating SIs and identification of reasons for observed differences are essential for designing better new SIs and for formulating appropriate corrective actions at existing sites.

The purpose of the present study has been to develop a data base on hazardous waste surface impoundment design and operating practices and to compare actual and projected performance for a selected number of facilities. Gaps in the existing data base and areas that most warrant research and development have been identified.

Two complementary approaches were used to define the state-of-the-art for hazardous waste surface impoundment technology: (a) case studies for a selected number of SIs, and (b) interviews with technical experts and individuals/organizations engaged in design, operation and regulation of SIs. The first approach involved review of the available data for a large number of SIs and resulted in the development of detailed Case Study "Reports" for a total of nine SIs and Case Study "Rejection Summaries" for 11 facilities. Though the latter were determined unsuitable for detailed case studies, they offered valuable lessons from the standpoint of SI siting, design, operation and regulation. The interviews-with-experts element of the study covered discussions with nine individuals and organizations.

A recently completed study for EPA involved assessment of the technology for constructing and installing cover and bottom liner systems for hazardous waste facilities.* One major element of the study involved the development of a data base through interviews of some 40 experts, both individuals and organizations, representing a spectrum of viewpoints on liners for hazardous waste facilities. Though topics such as liner material selection, manufacturing, fabrication, and transportation to use site, as well as site preparation and foundation design were addressed to some extent, the primary emphasis of the effort was on installation practices and largely in connection with landfill applications. Also, because of budgetary and schedule constraints, some additional key experts who could have made significant contributions to the study were not included in the sample of experts interviewed. Accordingly, a secondary objective of the interview-with-experts segment of the present study was to extend the data compilation and analysis of the previous study to include discussions with the additional key experts who were identified but not previously contacted. The data acquisition discussions with these additional experts emphasized primarily the activities and considerations that precede the actual installation of a liner (i.e., material selection, manufacturing, fabrication, transportation to and storage at site, design, and site preparation) and focused on the use of liners (primarily flexible membrane liner or FML, and clay) in SI applications.

Many of the individuals who were interviewed or with whom discussions were held in connection with the case studies saw a great need for (1) systematic and continual compilation of design versus performance data on full-scale SIs and (2) transfer of these data and information on the latest developments in containment technology, design advances, and R&D needs to the user community (i.e., designers, liner installers, permitting agencies, owners/ operators, researchers, etc.). To this end, the present effort is a step toward the goal of establishing a much needed SI design versus performance tracking and information exchange system whereby the actual experience from operating sites and the perspectives of technical experts on SI design, operation, regulation, and R&D needs are made available to the user community.

This document is organized into seven sections and two Appendices. This first section reviews the background and the intended uses of this document. Section 2 presents the conclusions of the study, including R&D recommendations. Section 3 describes the methodology for data acquisition and identifies the agencies and organizations providing input to the study in connection with the inteviews-with-experts element of the program. Section 4 discusses the results of the case studies and presents individual assessment summaries for the cases reviewed. An overview of the professional opinions of the individuals and organizations interviewed is presented in Section 5. Sections 6 and 7 present, respectively, the detailed reports on the nine case studies and individual reports on discussions with technical experts and organizations interviewed. Appendix A contains background data on 11 sites reviewed in some depth but eliminated for consideration as case studies. Appendix B contains miscellaneous support data for the case study reports contained in Section 6.

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*Ghassemi, M., et al., "Assessment of Technology for Constructing and Installing Cover and Bottom Liner Systems for Hazardous Waste Facilities":

- Volume I - Data Base Development: Perspectives of Industry Experts, State Regulators, and Owners and Operators; May 1983.

- Volume II - Technical Analysis; April 1983.

Final Report prepared for EPA under Contract No. 68-02-3174, Work Assignment No. 109.

Note that the materials presented in Sections 5 and 7 in connection with the interviews represent primarily the professional opinions of the individuals and organizations interviewed and are presented without any change or discussion or attempt to present opposing viewpoints on certain controversial assertions. As noted above, the objectives of the interviews were primarily to expand the data compilation of the previous liner study to include discussions with additional experts with emphasis on SI technology, and to obtain the perspectives of those interviewed on relevant R&D needs. The interviews also proved extremely valuable in identifying candidate facilities for the case studies.

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SECTION 2

CONCLUSIONS AND R&D RECOMMENDATIONS

2.1 LESSONS FROM THE CASE STUDIES

- Adequate site investigation, good project planning during the design and construction phase, and rigorous execution of a comprehensive QA/QC are essential to developing successful facilities. Problems resulting from inadequate site investigation and poor design and construction practices cannot be fully and permanently corrected through piecemeal remedies applied as the problems surface.

- Construction supervision and inspection by competent and conscientious inspectors to ensure adherence to recommended specifications, and rigorous documentation and record-keeping are cornerstones of an effective QA/QC program. The program should cover all steps (i.e., planning, design, construction, etc.) leading to the development of a completed facility and should encompass all system elements, support facilities, operations and corrective measures (i.e., monitoring wells, leak detection subdrains, dredging, repairs, etc.).

- QA/QC programs for facilities lined with FML should emphasize liner-waste compatibility as a criterion for liner selection, proper installation procedures (particularly in the seaming step), and the use of protective cover (especially when the liner would be exposed to severe stresses of the elements).

- Unless properly designed, groundwater monitoring programs would not be reliable substitutes for subdrain leak detection systems. These systems would be more reliable in providing advance warning of a site failure, thus allowing appropriate corrective measures to be implemented in a timely fashion.

- The successful performance of surface impoundments at two of the facilities studied is attributable to: (1) use of a very impermeable clay as liner material; (2) extensive waste-liner permeability studies; (3) use of competent design, construction, and inspection contractors; (4) close scrutiny of all phases of design, construction, and QA inspection by the owner/operator; (5) excellent QA/QC and record-keeping during all phases of the project; and (6) good communication between all parties involved in establishing the sites.

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- Case studies documenting the performance of hazardous waste facilities (successes and failures) can provide the feedback needed for evaluating the performance of various designs and construction techniques and can yield valuable lessons for improving design, construction, monitoring and operating procedures.

- The nine case study facilities reviewed here were selected from a much larger number of sites that were screened for suitability to the study objective. Many facilities were rejected because of one or more of the following reasons: (a) not representing an engineered site, (b) presence of other actual or potential sources of pollution at the site, (c) little or no data available on the hydrogeological settings and site construction, and (d) no or insufficient monitoring data to enable performance evaluation. Based on the sample of SIs examined, these rejected facilities more accurately represent the existing SI practices than the nine case studies that were selected for design versus performance evaluation.

2.2 PROFESSIONAL OPINIONS AND EXPERIENCE OF EXPERTS

- Siting in suitable geological formations is the best protection and the first line of defense against groundwater contamination, regardless of whether the facility will be lined with FML, clay, or other liner types.

- In the "intragradient" design, in which the facility is intentionally located in the saturated zone, the high groundwater table provides a positive pressure that can prevent release and outward migration of leachate or waste in the event of failure.

- Geotechnical support should be a continuous effort covering not only site investigation and facility design but also the construction activities. The support is especially important in preparing construction specifications and during pond and borrow pit excavation, when major changes in soil properties must be detected and appropriate modifications made to the original design and construction specifications.

- Even with the soundest design and support studies, the adequacy of a completed facility cannot be guaranteed without assurance that the construction has been carried out according to specifications. This underlines the importance of an effective QA/QC program, the key elements of which should include thorough construction inspection, use of competent and conscientious inspectors, and detailed documentation and record-keeping.

- The most critical factor in clay liner construction is compaction under proper moisture conditions. Compaction should be aimed at eliminating all air spaces and not necessarily at achieving certain arbitrary Proctor density levels. Compaction wet of optimum is generally sufficient to ensure elimination of air spaces and development of a very impermeable liner.

- Desiccation cracking of clay is a highly site- and situation-specific problem that depends not only on the type of clay and its silt content but also on the moisture level and construction technique. Since liners are constructed in lifts and there is little chance for alignment of cracks in adjacent lifts, a limited number of shallow cracks that may go unnoticed during lift inspection should not present a major leakage problem.

- Selection of suitable liner material, use of proper installation procedures, rigorous QA/QC, and providing and maintaining protective cover for the liner are critical factors in ensuring a successful FML installation.

- Even though waste-liner compatibility tests provide valuable data for selecting a suitable FML, a problem often encountered is that the characteristics of the waste that will come in contact with the liner is not known at the time of design and that the characteristics may change during site operation. For these reasons, the compatibility issue should be re-examined any time the character of waste changes.

- Practical measures for mitigating the liner-waste incompatibility problems relate to good site design and operating practices and include waste segregation, pretreatment and banning disposal of certain wastes.

- FML field installation problems can be minimized by the use of experienced workers who will carry out the actual installation. Providing good field supervision and technical assistance to the installer, and minimizing field seaming by use of larger liner sections (whereby much of the seaming has been done in the fabricating plant) will also minimize problems.

- Providing and maintaining protective cover for a liner is extremely important in preventing damages as a result of the elements and minimizing problems because of vandalism, pinholes, animals, and chemical incompatibility.

- Use of FML in conjunction with clay in a double liner system would take advantage of the desirable properties of both liner types and compensate for the possible shortcomings of the individual systems. Where such combination systems have been used, the design calculations, however, rely solely on clay as the protector, assuming that FML would not be available as a backup system.

- Despite considerable improvements that have occurred in the recent past in leachate collection systems design and construction, the apparent sporadic plugging of the underdrain systems remains a problem area. At the present time, there is no practical corrective measure for restoring the hydraulic capacity when a sand and gravel drainage system is plugged.

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- Subdrain leak detectors, which permit direct obervation, have merits over monitoring wells (or other indirect methods) by allowing more rapid detection of failure, permitting monitoring over a relatively large area under the liner and yielding more reliable results. Unless groundwater monitoring is tailored to the specific hydrogeological and other features of a site, it may prove inadequate in providing a true picture of the background conditions and changes in water quality.

- The proposed California regulations, which require double lining with clay and FML in addition to siting in Class I areas is considered by some to be unnecessarily overstringent. This apparently excessive stringency is based on the state's experience that (1) even some well designed facilities that have used the state-of-the-art technologies have failed, (2) geological deposits are often discontinuous and the potential for lateral or vertical migration of waste cannot be fully eliminated, and (3) when damage occurs, the cost of clean up can be very high.

- The requirement for the use of FML in state regulations is primarily in response to the requirement in the current interim final RCRA regulations.

- A considerable amount of accumulated experience in the waste disposal field needs to be collected, analyzed and disseminated as a technical manual that discusses in some detail how all of the elements of facility site selection, design, construction, operation, monitoring, maintenance and repair fit together.

2.3 R&D RECOMMENDATIONS*

- Extension of the present study to include additional case studies and experiences of technical experts, with dissemination of the extended study results to practicing engineers, owners/operators of hazardous waste management facilities, regulatory agencies and active researchers.

- Evaluation and documentation of the effectiveness of various FMLs, seaming methods, QA/QC procedures for installation, and FML compatibility with various wastes/leachates under field conditions.

- Development and standardization of practical and economic waste-liner compatibility tests for use in liner selection and as a means for accepting or rejecting waste loads by facility operators. The effort should include development of practical tools for predicting the characteristics of leachates from landfilling of various waste types.

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*See Section 5.6 for elaboration and listing of additional R&D needs.

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- Investigation and documentation of the "intragradient" and the "hydraulic barrier" design concepts for landfills and surface impoundments.

- Identification of proper design, construction and operating practices that would minimize the potential for clogging of the leachate collection systems and development of corrective measures for clogged systems.

- Development of laboratory procedures and practical field methods for obtaining clay permeability data for use in design.

- Development of new concepts and protocols for early detection of site failures and corrective measures, and evaluation of currently proposed systems (e.g., resistivity and accoustical measurement methods) under actual conditions.

- Development of technical basis and criteria for proper design of groundwater monitoring systems with respect to number, location, and depth of monitoring wells.

- Development of reliable, maintenance free, and retrofittable techniques for monitoring the unsaturated (vadose) zone. This should be supplemented with an effort to compile and evaluate data on mobility, attenuation, and persistence of various waste constituents in both the vadose and saturated zones.

- Development of reliable and cost-effective methods for pinpointing the location of liner leaks, repairing leaks (especially in landfills), and mending liners that have been in contact with waste and/or the elements for a number of years.

SECTION 3

DATA COLLECTION AND DATA BASE DEVELOPMENT METHODOLOGY

3.1 CASE STUDIES

The SIs for the initial case studies were selected largely from those operating in the southwestern United States. The search for suitable cases was later expanded to include review of data files/sites in four other states located in the Gulf Coast, Northeast and the Plains States regions. In selecting specific impoundments, the following data sources were consulted:

- State data files.
- State Surface Impoundment Assessment (SIA) surveys.
- Background information collected and analyzed recently for a number of hazardous waste management facilities in connection with several recent projects sponsored by the Land Disposal Branch of EPA's Office of Solid Waste, including "Risk Assessment for RCRA Subtitle C Land Disposal Regulations and Regulatory Impact Analysis," "Preparation of Background Information on Hazardous Waste Management Facilities," "Assessment of Technology for Constructing and Installing Cover and Bottom Liner Systems for Hazardous Waste Facilities," and "Waste Stream Description and Categorization."
- Technical experts (largely in connection with the interview-with-experts segment of the program).

Twenty-eight facilities were selected as potential candidates for case studies based on consultations with the above data sources. These sites were further screened by means of exploratory discussions with state regulatory agencies and facility owners/operators, and the following factors:

- Amount of data available
- Representation of a range of SI service types
- Type of liner (including no liner) used
- Types of hazardous waste handled
- Design and construction practices used

- Facility performance
- Absence of litigation
- Anticipated level of cooperation from owner/operator

The preliminary screening eliminated eight sites (Table 1) from further consideration. These sites were rejected because of multiple potential sources of pollution (three sites), ongoing litigation (two sites), lack of operating data because of the newness of the sites (two sites) and recent site closure (one site). The previously collected data on the remaining 20 sites were then supplemented with additional data obtained from state agencies, owners and operators and used to prepare detailed assessments for these sites. As a result, 11 additional sites were eliminated and detailed case study and assessment summary reports were prepared for the remaining nine sites.

Analysis of the data for the 11 rejected sites indicated that although the sites were not suitable for design versus performance analysis, they nevertheless offered some valuable lessons from the standpoint of program objective. Table 2 presents background information on 11 facilities that were subjected to detailed evaluation and rejected as unsuitable for the case studies, primary reasons for rejection are included. As noted in Table 2, these sites were generally found unsuitable for performance analysis because of the absence of adequate monitoring data (Facility A), multiple potential sources of contamination (Facilities B, D and I), recent changes in operating practice that eliminated discharge of hazardous waste to ponds (Facility C), refusal of the owner or operator to participate in the study (Facilties E, F, G, J and K), and other factors (Facility H). More detailed background information on the rejected sites and the basis for rejection are contained in individual site "rejection summaries" which are presented as Appendix A.

Case study reports on the nine facilities evaluated in detail (Case Studies No. 1 through No. 9) are contained in Section 6 and discussed in Section 4. The case study report for a site is essentially a compilation of all available relevant data for that site and is the basis for performance assessment. Depending on the amount of data available, the report contains some or all of the information categories shown in Table 3. Except for Case Study No. 9, the draft case study reports were submitted to the site owners/operators for review to assure accuracy and completeness and to provide them with an opportunity to expand or supply additional information or clarification on the various topics covered. The draft report for Case Study No. 9 was sent for review to the federal regulatory agency which licenses the facility and which provided data for use in the project. The draft report on Case Study No. 6 was sent to both the state and the owner/operator for review. In transmitting the draft reports, the reviewers were requested to submit their comments by a specified date (usually 2 to 4 weeks). It was stated in the transmittal letter that if no comments were received before the indicated date, it would be assumed that the draft report is correct and meets the approval of the reviewers. Except for Case Study No. 2 for which no comments were received on the draft report from the owner/operator, comments were received from reviewers and were incorporated in the case study reports which are presented in Section 6.

TABLE 1. FACILITIES ELIMINATED FROM FURTHER CONSIDERATION IN THE PRELIMINARY SCREENING

Facility	Waste Type	Liner Type	Leak Detection	Groundwater Monitoring	Basis for Elimination
Commercial hazardous waste disposal facility	Various industrial hazardous wastes	Various FMLs*	Yes	Yes	Company involved in litigation with the state
Agricultural chemical formulation facility	Pesticide rinse-waters	Bentonite	No	Yes	The system placed in service only recently
Aircraft manufacturing facility	Various hazardous wastes	PVC	No	Yes	Possible Superfund litigation
Commercial hazardous waste disposal facility	Petroleum and chemical industry wastes	In situ clay	No	Yes	SI performance difficult to evaluate because of other technologies (landfills and land farming) on site
Aircraft/Aerospace manufacturing	Various hazardous wastes	FML	Yes	Yes	SI operation began very recently (Spring 1983)
Circuit board manufacturing	Metal wastes	FML	No	No data	Plant recently closed down
Commercial hazardous waste disposal facility	Various industrial wastes	Clay	No	Yes	Other technologies (landfills and land farming) located on site
Sulfuric acid plant	Acidic wastes	FML	No	Yes	Facility built on waste piles from an abandoned copper smelting operation

*Flexible Membrane Liners

TABLE 2. FACILITIES EVALUATED BUT REJECTED AS CASE STUDY SITES

Facility Designation	Facility Type	Waste Type	Liner Type	Leak Detection	Groundwater Monitoring	Primary Reason for Rejection
A	Hydrometallurgical processing plant	Acid wastes	30-mil reinforced Hypalon	No	Yes	SI performance could not be evaluated because the groundwater monitoring system was just installed
B	Olive processing plant	Brines	Double-lined with 10-mil polyethylene sheets; liners separated by 2 ft of sand on side slopes and 1 ft of sand on the bottom	Yes	No	Irrigation water from adjacent lands influencing leak monitors
C	Chemical manufacturing plant	Acid wastes with heavy metals content	Butyl rubber	No	Yes	The owner/operator declined to participate in the study indicating that no hazardous waste has been received since new liners were installed in mid-1982, and the SIs currently contain no hazardous liquids or solids
D	Copper products	Acidic metal-treating wastes	CPE* placed on 12 inches of clay and 12 inches of sand	Yes	No	This site is located adjacent to site for Case Study No. 1 and has the same general design and operating history and hydrogeological characteristics. Inclusion of this

(Continued)

TABLE 2. FACILITIES EVALUATED BUT REJECTED AS CASE STUDY SITES (Continued)

Facility Designation	Facility Type	Waste Type	Liner Type	Leak Detection	Groundwater Monitoring	Primary Reason for Rejection
D	Copper Products (Continued)					facility as a full case study was considered to bias the sample of facilities studied in the program
E	Copper smelter	Acidic metal-bearing wastes	Hypalon	Yes	Yes	The owner/operator declined to participate in the study and there were not enough data available from other sources
F	Electroplating facility	Electroplating sludges	HDPE[†]	No	Yes	The owner/operator declined to participate in the study and there were not adequate data available from other sources
G	Oil refinery	API separator sludge	Soil asphalt	No	Yes	The owner/operator declined to participate in the study and there were not adequate data available from other sources
H	Chemical plant	Corrosive, caustic wastes	CPE	Yes	Yes	The FML[‡] is underlain by reinforced concrete; the system is thus a tank and not a SI

(Continued)

TABLE 2. FACILITIES EVALUATED BUT REJECTED AS CASE STUDY SITES (Continued)

Facility Designation	Facility Type	Waste Type	Liner Type	Leak Detection	Groundwater Monitoring	Primary Reason for Rejection
I	Commercial hazardous waste disposal facility	Various chemical and petroleum industry waste	3-ft compacted clay	No	Yes	Due to presence of abandoned and existing land disposal operations on-site, SI performance could not be evaluated
J	Agricultural fertilizer manufacturing plant	Acid wastes, metals, fluoride	Compacted clay	No	Yes	The owner/operator declined to participate in the study and there was insufficient information available from other sources
K	Chemical manufacturing plant	Caustic aqueous solutions	Compacted clay, soil cement, 10-mil PE[§] and 45-mil CPE	Yes	No	The owner/operator declined to participate in the study and there were insufficient data available from other sources

[*] Chlorinated polyethylene

[†] High-density polyethylene

[‡] Flexible Membrane Liner

[§] Polyethylene

TABLE 3. TYPES OF INFORMATION SOUGHT FOR THE CASE STUDIES

- Basis for site selection:
    - Geotechnical and hydrogeological considerations/studies, including results of any soil boring tests, modeling effort, and environmental impact analysis.
- Basis for selection of the design firm (and construction/installation contractors).
- Criteria used and basis for design:
    - Design objective and purpose of impoundment (disposal, storage, treatment);
    - Waste characteristics data (flow, composition, etc.);
    - Hydrogeological considerations (e.g., distance to groundwater, precipitation, evaporation, temperature, etc.);
    - Waste-liner compatibility considerations;
    - Soil permeability and leachate attenuation test results used:
    - Regulatory/permit agencies requirements;
    - Cost considerations;
    - Etc.
- Description of design and design specifications:
    - Unit size, dimensions, and configuration;
    - Liner type, characteristics, and recommendations for installation;
    - Specifications for foundation preparation, leak detection system, and liner backfill placement;
    - Inlet/outlet, aeration unit, and other appurtenances including systems for diversion of surface runoff, prevention of vandalism and animal damage;
    - Observation wells and monitoring systems;
    - QA/QC specifications;
    - Etc.
- Description of as-built facility and related matters:
    - Modifications to and deviations from the recommended design and specifications, and the basis for such modifications and deviations;

(Continued)

TABLE 3. TYPES OF INFORMATION SOUGHT FOR THE CASE STUDIES (Continued)

  - Problems encountered which had not been anticipated or adequately addressed in design, and mitigation measures used;
  - Level of QA/QC and competent inspection actually employed.

- Performance data and operating experience:
  - Evidence for liner/system inadequacies or failures (groundwater monitoring data and leak detection information);
  - Operating difficulties encountered and mitigation measures used;
  - The adequacy and reliability of the monitoring system to detect or forewarn problems;
  - Inspection and maintenance programs;
  - Etc.

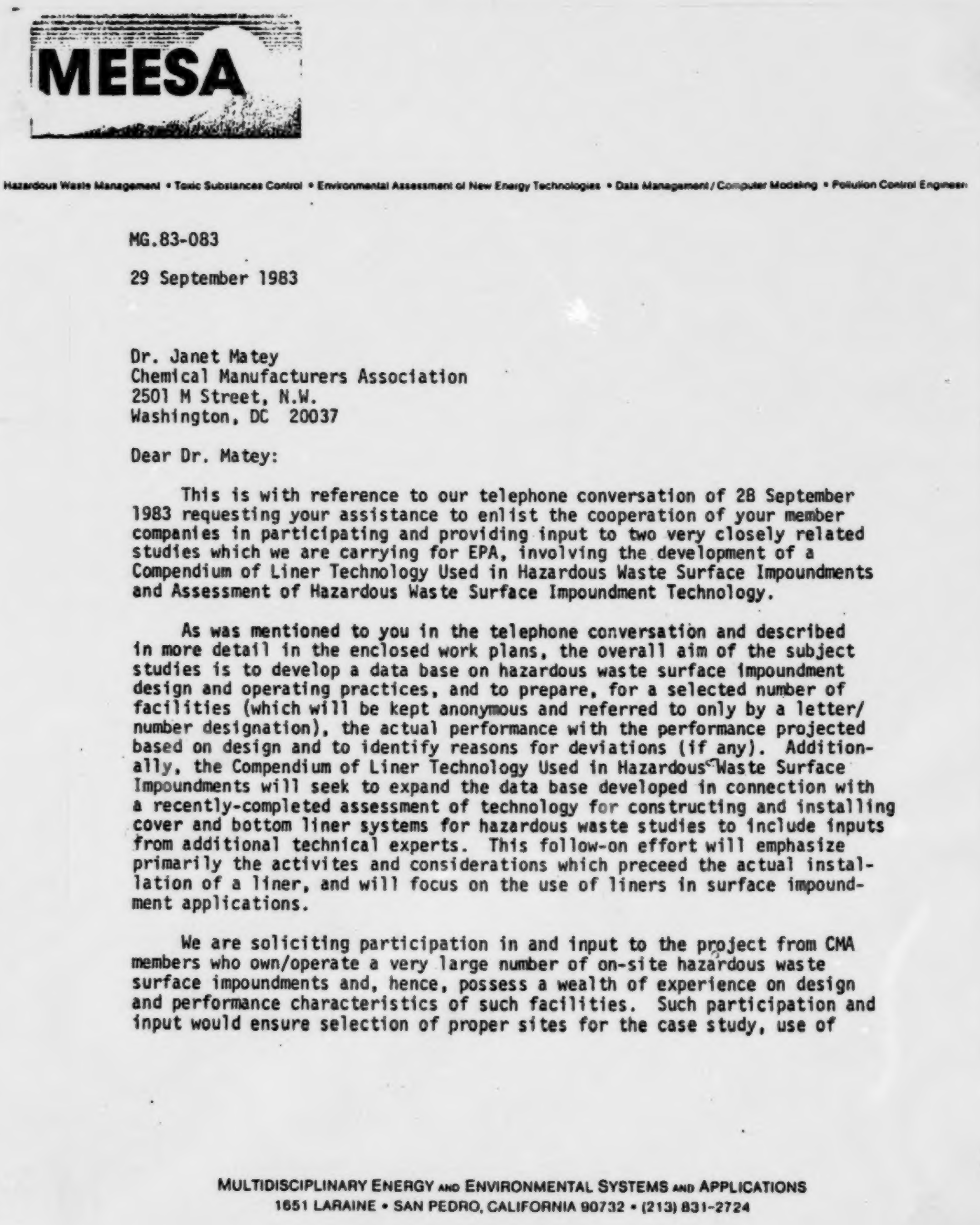
The identity of the case study sites was of little consequence to the project objective. Thus to promote cooperation of the owners/operators, all sites were kept anonymous and are referred to only by letter or number designations.

3.2 INTERVIEW WITH EXPERTS

This phase of the effort solicited expert perspective on factors affecting SI performance and deviation from design predictions. Information was sought from those most intimately involved in the design, construction, operation and regulation of hazardous waste SIs. A number of experts not previously interviewed in connection with the precursor liner/cover technology assessment effort (see Section 1) were identified through discussions with EPA and various state agencies, literature search and owner/operators of facilities reviewed in connection with the case studies. The potential interviewees were then contacted ("screened") by telephone to gauge their interest in the study and the type and relative value of their potential inputs. Where some strong interest was indicated, the telephone discussion was followed by a formal request letter to which was attached a copy of the "work plan" providing a more elaborate description of the study and its objectives. A copy of a typical letter is reproduced as Table 4.

Although a larger number of individuals/organizations were contacted, only the nine listed in Table 5 cooperated with the study and granted interviews. The non-respondents and those who stated reasons for declining to participate in or provide inputs to the program included the Chemical Manufacturers Association (CMA), National Water Well Association (NWWA), one FML installer, one FML manufacturer/fabricator, one commercial hazardous waste facility owner/operator, and one chemical manufacturer with on site

TABLE 4. TYPICAL LETTER REQUESTING PARTICIPATION IN AND INPUT TO THE PROGRAM



MEESA

Hazardous Waste Management • Toxic Substances Control • Environmental Assessment of New Energy Technologies • Data Management/Computer Modeling • Pollution Control Engineer

MG.83-083

29 September 1983

Dr. Janet Matey
Chemical Manufacturers Association
2501 M Street, N.W.
Washington, DC 20037

Dear Dr. Matey:

This is with reference to our telephone conversation of 28 September 1983 requesting your assistance to enlist the cooperation of your member companies in participating and providing input to two very closely related studies which we are carrying for EPA, involving the development of a Compendium of Liner Technology Used in Hazardous Waste Surface Impoundments and Assessment of Hazardous Waste Surface Impoundment Technology.

As was mentioned to you in the telephone conversation and described in more detail in the enclosed work plans, the overall aim of the subject studies is to develop a data base on hazardous waste surface impoundment design and operating practices, and to prepare, for a selected number of facilities (which will be kept anonymous and referred to only by a letter/ number designation), the actual performance with the performance projected based on design and to identify reasons for deviations (if any). Additionally, the Compendium of Liner Technology Used in Hazardous Waste Surface Impoundments will seek to expand the data base developed in connection with a recently-completed assessment of technology for constructing and installing cover and bottom liner systems for hazardous waste studies to include inputs from additional technical experts. This follow-on effort will emphasize primarily the activites and considerations which preceed the actual installation of a liner, and will focus on the use of liners in surface impoundment applications.

We are soliciting participation in and input to the project from CMA members who own/operate a very large number of on-site hazardous waste surface impoundments and, hence, possess a wealth of experience on design and performance characteristics of such facilities. Such participation and input would ensure selection of proper sites for the case study, use of

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TABLE 4. TYPICAL LETTER REQUESTING PARTICIPATION IN AND INPUT TO THE PROGRAM (Continued)

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the most relevant available information and objective analysis of the surface impoundment technology based on "real world" data. Depending on the extent and the form of data available for a site, we anticipate that the man-hour demand on an owner/operator for providing data for use in our studies and for reviewing the draft report on a case study or an "interview" could vary from as little as 2 to perhaps as much as 16 hours.

We trust that you will find the enclosed work plans helpful in explaining the nature and objective of our studies, and we look forward to the participation of CMA and its members in these studies.

Sincerely,

Masood Ghassemi, Ph.D., P.E.
Principal and Technical Director

MG/mt

Enclosures

C: Carlton Wiles (U.S. EPA; Cincinnati, OH)

TABLE 5. INDIVIDUALS/ORGANIZATIONS INTERVIEWED

Interview No.	Name and Address	Interviewee(s) and Phone	Date	Background/ Expertise
1	Louis J. Capozzoli & Associates 10555 Airline Highway Baton Rouge, LA 70816	Dr. Louis Capozzoli Mr. Glynn Gautreau (504) 293-2460	10 October 1983	Geotechnical engineers; landfill and impoundment design and construction inspection. Over 2,500 soil foundation projects performed.
2	State of Ohio EPA Public Water Supply/ Div. of Hazardous Waste Materials 361 E. Broad Street Columbus, OH 43216	Mr. Russel Stein (614) 466-8307 Mr. Christopher Bowers (614) 462-8413	12 October 1983	State agency has jurisdiction over 300 hazardous waste management facilities.
3	Staff Industries, Inc. 78 Dryden Road Upper Montclair, NJ 07043	Dr. Charles Staff (201) 744-5367	13 October 1983	Fabricator/installer of Hypalon, CPE, and PVC. Dr. Staff is often referred to as "father" of FML industry.
4	Emcon Associates 1455 Schulkill Road Pottstown, PA 19464	Mr. John Pacey (215) 327-4340	8 November 1983	Designer of numerous hazardous waste management facilities.
5	State of Louisiana Hazardous Waste Management Division P.O. Box 44066 Baton Rouge, LA 70804	Mr. Gerald Healy (504) 342-1227	10 November 1983	State has jurisdiction over several hundred hazardous waste facilities; state discourages use of surface impoundments.

(Continued)

TABLE 5. INDIVIDUALS/ORGANIZATIONS INTERVIEWED (Continued)

Interview No.	Name and Address	Interviewee(s) and Phone	Date	Background/ Expertise
6	Wehran Engineering 666 East Main Street Middletown, NY 10940	Mr. Robert Mutch Mr. Salvatore Arlotta (914) 343-0660	11 November 1983	Leading design firm specializing in land disposal facilities; company holds patent on its hydraulic barrier concept.
7	Moore & Tabor 4530 E. La Palma Ave. Anaheim, CA 92807	Mr. Return Moore Mr. Don Clark (714) 779-2591	22 November 1983	Consulting engineers and geologists; 30 years of experience with the design of earthern dams, reservoirs, and disposal facilities.
8	IT Corporation 336 W. Anaheim Street Wilmington, CA 90744	Mr. David Bauer (213) 830-1781	28 November 1983	Commercial operator of many hazardous waste disposal facilities.
9	State of California Water Resources Control Board/Department of Health Services P.O. Box 100 Sacramento, CA 95801	Mr. Robert Ford Mr. Eric Findlay Ms. Charlene Herbst Mr. Jim Parsons Mr. Elgar Stephens Mr. Jim Sundberg Mr. Gil Torres	16 December 1983	Regulator of many hazardous waste facilities; proposing new regulations for Phase II RCRA authorization.

SI operations. Where reasons were stated, they mostly related to either a lack of adequate resources and man-power, or to a claim of confidentiality and proprietary nature of operation and data.

Except for one interviewee who responded to a set of written questions, the interviews involved face-to-face discussions which took place in a very informal atmosphere. As noted in Table 5, in most cases more than one individual represented the participating organization. Depending on the expertise of the interviewee, the data acquisition discussions generally covered some or all of the following topics:

- Surface impoundment versus landfill
- Site selection
- Geotechnical evaluation
- Design criteria and considerations
- Quality assurance and quality control
- Liner material selection and liner-waste compatibility problems
- Site preparation and liner installation
- Research and development needs
- Regulatory considerations

Following each interview, an interview summary report highlighting the key and relevant points of the discussion was drafted, based on notes taken during the interview. As with the draft case study reports, the draft interview summary reports were forwarded to the interviewees for review. Changes suggested by the interviewees were generally minor and were incorporated in the final interview reports which are presented in Section 7. A typical letter requesting review of the draft interview report is reproduced as Table 6.

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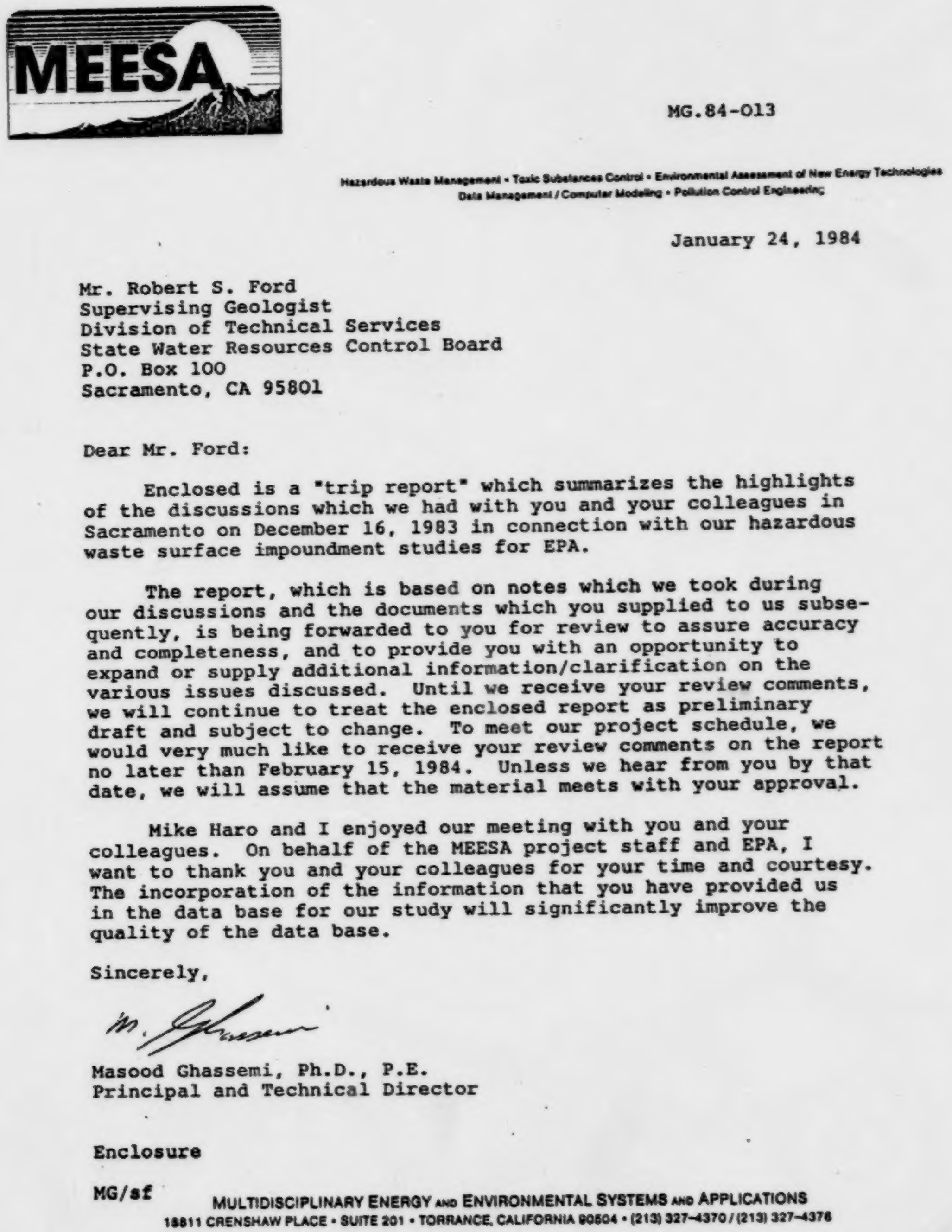
TABLE 6. TYPICAL LETTER REQUESTING REVIEW COMMENTS ON DRAFT INTERVIEW REPORTS



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MG.84-013

January 24, 1984

Mr. Robert S. Ford
Supervising Geologist
Division of Technical Services
State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95801

Dear Mr. Ford:

Enclosed is a "trip report" which summarizes the highlights of the discussions which we had with you and your colleagues in Sacramento on December 16, 1983 in connection with our hazardous waste surface impoundment studies for EPA.

The report, which is based on notes which we took during our discussions and the documents which you supplied to us subsequently, is being forwarded to you for review to assure accuracy and completeness, and to provide you with an opportunity to expand or supply additional information/clarification on the various issues discussed. Until we receive your review comments, we will continue to treat the enclosed report as preliminary draft and subject to change. To meet our project schedule, we would very much like to receive your review comments on the report no later than February 15, 1984. Unless we hear from you by that date, we will assume that the material meets with your approval.

Mike Haro and I enjoyed our meeting with you and your colleagues. On behalf of the MEESA project staff and EPA, I want to thank you and your colleagues for your time and courtesy. The incorporation of the information that you have provided us in the data base for our study will significantly improve the quality of the data base.

Sincerely,

M. Ghassemi

Masood Ghassemi, Ph.D., P.E.
Principal and Technical Director

Enclosure

MG/sf

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SECTION 4

DISCUSSION OF CASE STUDIES

This section of the report, which is based on the individual case study reports contained in Section 6, presents: (1) general background information on the facilities covered, (2) an overview of the SI technology for the cases reviewed, and (3) technical assessments for each of the nine case studies.

4.1 GENERAL BACKGROUND INFORMATION ON THE FACILITIES COVERED

Tables 7, 8 and 9 present some background information on the nine case study sites. Table 7 contains general information on these sites, including the characteristics of wastes handled. As noted in the table, these SIs serve a variety of industries, handle different waste types and volumes, are used for disposal or treatment purposes, and range in age from less than 2 to more than 30 years. Some general information on the environmental setting (surrounding land use, geology, and hydrology) for the SIs is presented in Table 8 to indicate the spectrum of conditions represented by the sites considered. The SI technology information on the sites appears in Table 9. The case studies cover a range of liner types and designs (single versus double liner, clay versus Flexible Membrane Liners (FML) versus clay and FML) and leak detection systems. The extent of ground water monitoring also varies from use of no observation wells to use of multiple wells at strategic locations.

4.2 OVERVIEW OF THE SI TECHNOLOGY FOR THE CASES REVIEWED

This section reviews the information contained in the case study reports and provides an overview of the SI technology employed. For discussion purposes, the relevant case study information is reviewed under the following headings:

- Basis for site and contractor selection
- Basis for design and design specifications
- Construction and QA/QC inspection and documentation
- Performance and operating experience

TABLE 7. CASE STUDY FACILITIES - GENERAL FEATURES AND WASTE CHARACTERISTICS

Case Study No.	Type of Facility	Type of SI (No. and Function)	Year SI Placed in Service	SI Size (Acres)	Waste Type	Waste Quantity
1	Electrolytic metal refining plant	Small disposal pond	1972	0.4	Acidic process liquor and sludge waste (pH <2) high in heavy metal content	A total of 843,750 gallons in 1982
		Disposal pond	1979	1.1	Acidic process liquor and sludge waste (pH <2) high in heavy metal content	
2	Pesticide formulation and distribution plant	Pesticide washdown evaporation disposal pond	1979	<0.1	Pesticide rinsewater	Batch operation (400 gallons/day maximum)
		Pesticide rinsewater evaporation disposal pond	1982	<0.1	Pesticide rinsewater	Batch operation (400 gallons/day maximum)
3	Commercial hazardous waste disposal facility	Site A: 8 impoundments used for settling, storage, and sludge disposal	1951	15	Oily water and brines, alkaline and acid wastes, heavy metals, paint sludge, tank bottom sediments, cyanide, pesticides, and other chemical wastes	A total of 53,000,000 gallons in 1982
		Site B: 7 evaporation disposal ponds	1971	74	Oil water and brines, alkaline and acid wastes, heavy metals paint sludge, tank bottom sediments, cyanide, pesticides, and other chemical wastes	
4	Agricultural fertilizer manufacturing plant	11 settling ponds used to remove gypsum	1965	14	Production water from ammonium phosphate/phosphoric acid plant with pH <2 and high radionuclides content	20,000 gallons/day
		One evaporation pond (treatment)	1976	8	Wastewaters from plant boilers, water treaters, and nitric and sulfuric acid plants (pH <2, high in radionuclides)	130,000 gallons/day
		One cooling pond (treatment)	1976	38	Same as gypsum SIs	10,000 gallons/day

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TABLE 7. CASE STUDY FACILITIES - GENERAL FEATURES AND WASTE CHARACTERISTICS (Continued)

Case Study No.	Type of Facility	Type of SI (No. and Function)	Year SI Placed in Service	SI Size (Acres)	Waste Type	Waste Quantity
5	Mineral ore mining/ manufacturing plant	5 low-head solar ponds (treatment and storage)	1972	90	Mineral liquor tailings with high arsenic and boron content	A total of 50,000,000 gallons/month to Ponds A-E, 4, and 5
		High-head evaporation pond (treatment and storage)	1975	80	Mineral liquor tailings with high arsenic and boron content	
		High-head evaporation pond (treatment and storage)	1976	100	Mineral liquor tailings with high arsenic and boron content	
		Evaporation pond (treatment and storage)	1980	120	Acid plant wastewater with high arsenic and boron content	12,000,000 gallons/month
6	Commercial hazardous waste disposal facility	Evaporation pond (disposal)	1980	5	Geothermal muds and brines, wastewater treatment sludge, tank bottom sediments, cooling tower blowdown sludge and oil drilling muds	9,850,000 gallons in 1982
		Disposal pond (currently used for land treatment)	1980	5	Geothermal muds and brines, wastewater treatment sludge, tank bottom sediments, cooling tower blowdown sludge and oil drilling muds	
		Disposal pond (currently used for land treatment)	1981	5	Geothermal muds and brines, wastewater treatment sludge, tank bottom sediments, cooling tower blowdown sludge and oil drilling muds	
7	Agricultural fertilizer manufacturing plant	Cooling pond (treatment)	1974	100	Process water from phosphoric acid plant with pH <2 and high fluoride content	40,000 gallons/ minute (maximum)
		Initial gypsum pond (disposal)	1974	150	Gypsum slurry with pH <2 and fluoride and phosphorus content	NA
		Expansion gypsum pond (disposal)	1980	200	Gypsum slurry with pH <2 and fluoride and phosphorus content	NA
8	Chemical production plant	2 equalization/retention basins (treatment)	1976	3.5	Wastes high in organic nitrogen content and varying pH, resulting from synthetic fiber production	3,000 gallons/ minute
9	Uranium mining/ milling	Tailings pond (disposal)	1980	64	Acidic tailings slurry containing kerosene and radium 226	NA

NA: No data available.

TABLE 8. CASE STUDY FACILITIES - ENVIRONMENTAL FEATURES

Case Study No.	General Setting	Geology	Hydrology	Other Nearby Potential Sources of Pollution
1	Desert region of the Southwest. The area heavily industrialized with several major hazardous waste generators adjacent to the plant	An alkaline, loamy fine sand extending about 70 feet beneath the site and having a permeability of 10^{-2} cm/sec. Also beneath the site are a few thin clay and silt lenses	Rainfall averages 8.8 inches annually. A complex ground water system, consisting of a water table aquifer (80 feet beneath the site) and a semi-confined aquifer, underlies the facility. The upper aquifer recharges the lower one which is the principal source of municipal and industrial water in the area	On site bentonite-lined cooling ponds. Abandoned (1972) unlined wastewater pond. Evaporation ponds adjacent to this site
2	An alluvial valley of the Southwestern U.S. Nearby land uses include agriculture, commercial, and residential	NA	NA	None
3	Surrounding lands are marshy, and nearby land uses include solid waste disposal and flood control	Site A underlain by 150 to 700 feet of organic clays (permeability ranges from 10^{-5} to 10^{-8} cm/sec), followed by marine sandstone and shale bedrock. Site B has 1 to 4 feet of silty clayey sands followed by 700 to 800 feet of sandy and silty clay (permeability ranges from 10^{-6} to 10^{-8} cm/sec)	Poor quality ground water exists 3 to 5 feet below ground surface. Ground water at Site A flows to the northeast. At Site B, the hydraulic gradient is in the form of an oval mound over the site. Ground water is not used. The site is near a large bay and is separated from it by marshy land and flood control canals	A commercial hazardous waste landfill immediately adjacent to Site A SIs
4	An alluvial valley of the Southwest. Surrounding lands are flat and are primarily for agricultural purposes.	Soil beneath the site consists of 1 to 5 feet of clay with a high calcium carbonate content followed by 150 to 200 feet of sandy soil with silt and clay lenses.	Ground water exists 30 feet below ground surface in a poorly defined perched aquifer, at 150 feet (normal water table), and at 300 to 1000 feet in a confined aquifer. Water from the perched aquifer and the unconfined aquifer is used extensively for irrigation, domestic, and industrial consumption. A small slough is located along the plant's border.	Extensive irrigation of agriculture land surrounding site. Plant wastewaters discharged to a nearby stream from 1959 to 1977. Two abandoned (1974) on-site percolation ponds.

(Continued)

TABLE 8. CASE STUDY FACILITIES - ENVIRONMENTAL FEATURES (Continued)

Case Study No.	General Setting	Geology	Hydrology	Other Nearby Potential Sources of Pollution
5	A desert region with local relief of about 15 feet.	Alluvial deposits in the vicinity consists of gravel, sand, silt, and clay. Several faults are located near the facility.	The clean sands and gravel beneath the SIs contain small amounts of ground water at levels of about 300 feet.	None.
6	A sparsely vegetated desert area. Adjacent lands are vacant desert.	The SIs are underlain by an ancient lake bed consisting of alternating, unweathered clay, silt, and sandy silt soils to a depth of 100 feet. Permeability ranges from 10^{-4} to 10^{-8} cm/sec.	Depths to ground water on the eastern and western site boundaries are 30 feet and 90 feet, respectively. The ground water is saline and is not of beneficial use in the area.	None.
7	Located in the Southeast. Surrounding lands are used for farming and by the chemical industry.	Three primary strata: natural levee deposits 5 to 10 feet thick; back-swamp clays to about 120 feet and with a permeability of about 10^{-9} cm/sec; and substratum sands extending to 260 feet.	Rainfall averages 60 inches annually. Evaporation rate is 48 inches/year. Ground water exists at ground surface. Fresh water aquifer is at 260 feet.	None.
8	Marshy region of the Atlantic Coast (heavily industrialized).	Soils contain large amounts of previously deposited wastes (mainly fly ash and slag) in a clayey sand mixture.	Perched ground water is at 15 to 30 feet, but is not used for industrial or domestic purposes.	Extensive on site and off-site disposal by present and previous occupants (since early 1900's) have raised the ground surface elevation 20 to 30 feet.
9	Semi-desert, remote area of a northwestern Plain State with a dry, cold climate	Interbedded mudstone, siltstone, and sandstone with a permeability of about 10^{-5} cm/sec.	Water table is at 70 to 150 feet below ground surface; recharge is by surface runoff.	None.

NA: No data available.

TABLE 9. CASE STUDY FACILITIES — LINER AND MONITORING SYSTEMS

Case Study No.	Type of SI	Liner Type	Design/Installation Data Available	Leak Detection System	Ground Water Monitoring
1	Small disposal pond	Originally lined with a 20-mil DuPont 3110 FML; replaced in 1981 with a Goodrich 30-mil HP-6 nylon-reinforced FML	Some data on liner design and installation available	None	Three wells each around the perimeter of the small and large SIs (installed in 1982) and one background well
	Disposal pond	DuPont 3110 FML	Little data available	None	
2	Washdown pond	Bottom and slopes of pond lined with 2 layers of Goodyear 30-mil PVC. Secondary liner (bottom only) is a Goodyear 30-mil PVC	Detail drawings available (no specifications) on pond, liner, and detection system	1-ft gravel layer and one 3-inch perforated PVC pipe extending half way across the pond and connecting to an observation well	None
	Rinse-water pond	Primary liner is a 20-mil CPE. Secondary liner is a 10-mil PVC	Detail drawings available (no specifications) on pond, liner, and detection system	A 1-ft sand layer; a 4-inch perforated PVC pipe connected to an observation well	None
3	Site A impoundments	Clay	Detailed design and construction information available for impoundment levees. Otherwise, little data available.	A sub rain trench and collection sump were installed along the eastern edge of Site A in 1971. Escaping liquids are automatically pumped back into the SIs	Three wells
	Site B	Clay	Detailed design and construction information available for impoundment levees. Otherwise, little data available	None	14 wells around SIs
4	Settling ponds	Unlined. Limited data indicate that a waste-soil seal (10^{-6} cm/sec permeability) exists beneath the ponds	Little design/installation data available	None	None
	Evaporation and cooling ponds	Lined with Pantasote 12-mil PVC on the bottom and Carlisle Tire & Rubber Co. 30-mil Dacron-reinforced EPDM on the side slopes. Secondary liner is 1-ft compacted clay	Complete and detailed pond and liner design and construction specifications/drawings available	Three V-ditch drains lined with 30-mil PVC, 3-inch drain pipe, and monitoring wells	None

(Continued)

TABLE 9. CASE STUDY FACILITIES — LINER AND MONITORING SYSTEMS (Continued)

Case Study No.	Type of SI	Liner Type	Design/Installation Data Available	Leak Detection System	Ground Water Monitoring
5	Solar ponds	10-in compacted clay	Complete and detailed pond and liner design and construction specifications/drawings available.	None	12 wells used to monitor ground water in the plant vicinity
	Evaporation ponds	18-in compacted clay	Complete and detailed pond and liner design and construction specifications/drawings available	A gravel collector section overlying a continuous polyethylene liner placed in graded V-ditches connecting to a monitoring basin via a perforated pipe.	
6	Evaporation and disposal ponds	In situ clay with a minimum thickness of 2 feet. Recompacted clay embankments	Some pond and liner design and construction specifications/drawings available	None.	Four wells surrounding SIs
	Disposal pond	In situ clay with a minimum thickness of 2 feet. Recompacted clay embankments	Some pond and liner design and construction specifications/drawings available	None	
	Disposal pond	In situ clay with a minimum thickness of 2 feet. Recompacted clay embankments	Some pond and liner design and construction specifications/drawings available.	None	
7	Cooling and gypsum ponds	In situ clay and recompacted clay embankments	Complete pond and liner design and construction specifications/drawings available	None	20 wells surrounding SIs
8	Equalization basins	2 feet of compacted clay overlain by 50-mil EPDM	Some pond and liner design specifications available	Clay tiles with 1/4 inch holes on 3/8-inch centers	10 monitoring wells; 3 downgradient, 2 upgradient, and 5 in the general vicinity
9	Tailings pond	30-mil PVC on base and 30-mil reinforced Hypalon on side slopes	Detailed design and earthwork construction data available (drawings, inspections, etc.); however no FML installation data available	Five underdrains with 2-in. perf. pipes and gravel spaced 200 ft. apart	6 monitoring wells; 1 supply well also monitored

4.2.1 Basis for Site and Contractor Selection (see Table 10)

For cases involving on site disposal (Cases 1, 2, 4, 5, 7, 8 and 9), land availability on site appears to have been the primary reason for on site location of the SIs. Any siting studies performed for these sites were done to establish justification for site location or to develop basis for design and mitigation measures. Older facilities (Cases 1, 6 and 8) were designed and placed in service at a time when no rigorous regulations were in effect and hence no detailed siting studies or environmental impact analyses were required or performed for these sites. Proximity to the industries served was stated to have been a reason for site selection for the two commercial disposal sites.

Presumably due to cost considerations, nearly all smaller on site disposal facilities were designed by the owner and constructed by the owner using contract labor. Outside consultants were used to design, provide geotechnical support, install liners and construct larger on site facilities (Cases 5, 7, 8 and 9) and off site commercial facilities (Cases 3 and 6). Reputation of the contractors and their related work experience in the region or with similar projects were reportedly the bases for contractor selection in Cases 4, 5 and 7. Information was generally unavailable on the extent that the contractor's price or bid was a factor in selecting contractors for construction or liner installation.

4.2.2 Basis for Design and Design Specification (see Table 11)

For facilities using FML (Cases 1, 2, 4, 8 and 9), the selection of the particular liner material was generally based on liner-waste compatibility data provided by the suppliers. No liner-waste compatibility tests were conducted by the site owner prior to liner selection in Cases 1, 2 and 9. It could not be determined whether such tests were conducted in connection with liner material selection in Cases 4 and 8. Although QC specifications for Case 4 required testing of all FML material (including that used in the subdrains) with a solution similar to the expected waste, no test results could be located nor could the owner confirm that such tests were performed.

Soil permeability tests were conducted in connection with site investigation or for developing basis for design in Cases 3 through 7. Such tests were not conducted in Cases 1 and 2 and no information was available on whether such tests were conducted in Cases 8 and 9.

Some general and broad state design guidelines and state discharge permit requirements governed the design of SIs in Cases 2 through 7. No such requirement existed for site designs in Cases 1 and 8. Case 9, which is regulated and licensed by NRC, had to conform with extensive NRC guidelines and review requirements.

The QA/QC governing facility design varied from simple inspection by the owner in Case 1 to comprehensive specifications and guidelines in Case 5. No information was available on QA/QC specifications and procedures employed (if any) in Cases 2, 6 and 8.

TABLE 10. BASIS FOR SITE AND CONTRACTOR SELECTION

Case Study No.	Site Selection	Contractor Selection
1	On site land availability; no environmental impact assessment required or performed	Owner designed and constructed ponds using contract labor; ground water monitoring system installed by outside consulting firm
2	On site land availability, no environmental impact assessment required or performed	Owner designed and constructed ponds with local contract labor
3	Availability of reasonably priced land close to industries served; hydrogeological and environmental assessments performed as a part of site expansion	Several different consultants and contractors used to design levees, construct ponds, drill wells, etc.
4	On site land availability and the results of geologic-seismic, soils, and environmental investigations	Gypsum ponds designed by owner and constructed by a local contractor; evaporation/cooling ponds designed by owner, constructed by a contractor, and FMLs installed by an experienced installation contractor
5	On site land availability and the results of geotechnical and environmental assessments	All ponds were designed and inspected by the same geotechnical consultant because of their continued excellent performance; owner and three different contractors constructed ponds
6	The state performed a geologic survey and recommended areas especially suited to evaporation pond construction; operator purchased the only privately owned land within recommended areas and performed site investigation	Ponds designed by owner and constructed by an outside contractor; geotechnical consultants performed site investigations and construction inspection

(Continued)

TABLE 10. BASIS FOR SITE AND CONTRACTOR SELECTION (Continued)

Case Study No.	Site Selection	Contractor Selection
7	Pond location on site based on results of site investigations aimed at ensuring that sufficient and suitable storage volume was available on company-owned land to provide for plant operation through the year 2000	All ponds were designed by the same local geotechnical consultant because of their familiarity with gypsum pond design and extensive experience with soils in the area; the particular construction contractor was chosen because of its experience and reputation
8	On site land availability; no site investigations performed	Ponds designed by owner, constructed by a local contractor, and FML installed by local contractor
9	Tailings pond was located on site (adjacent to the mill) to facilitate waste disposal; hydrogeologic study performed to assess site suitability and provide basis for design	Pond designed by two different consulting firms, constructed by a contractor and the owner, and FML installed by an experienced installer

TABLE 11. BASIS FOR DESIGN AND DESIGN SPECIFICATIONS AND COSTS

Case Study No.	Liner-Waste Compatibility Testing	Soil Permeability Testing	Regulatory Requirements	QA/QC Specifications	Cost
1	None; liner selection based on local availability of FML and reported experience	None	None prior to pond construction; ground water monitoring required in 1981	None; owner review	Small pond: $15,000 to $20,000 (1972); large pond: $56,000 (1979); small liner replacement: $26,000 (1981)
2	None; FML liner selection based on data provided by manufacturer	None	State discharge permit required use of liners and leak detection system for ponds	NA	NA
3	None; selection of clay liners based on availability of local, low permeability clay material	Testing of in situ materials to develop basis for design conducted for "site B" ponds only	Drainage, permeability, monitoring, and inspection requirements established after all ponds began operation	Maximum lift thickness and compaction for levee construction.	NA
4	Acceptance tests (e.g., elongation, acid resistance, volatility, etc.) of PVC and EPDM performed as specified by third party; specifications called for a simulated waste and liner compatibility test (no test results were available)	None (testing of clay liners in the evaporation and cooling ponds after installation)	None prior to gypsum pond construction; state prohibits discharge to gypsum ponds not rendered impermeable and required FML for evaporation and cooling ponds	Inspection of subgrade, acceptance testing of FML prior to delivery, field and factory seam testing, and testing of subdrain materials	Evaporation and cooling ponds: $1,450,000 (1976) includes excavation and clay and FML systems; repair of cooling pond FML: $197,000 (1977)
5	Effects of wastewater on clay permeability were thoroughly investigated in the laboratory	Comprehensive testing of clay from stockpiles using pond liquor as permeating fluid to evaluate design permeability and effective porosity	State discharge permit specified freeboard limitations, drainage control, liner permeability, ground water monitoring, and closure of ponds once leakage in subdrains is detected	Include stockpile (borrow) material handling, site clearing, foundation preparation, excavation, dikes, subdrains, liner installation, etc.	NA

(Continued)

TABLE 11. BASIS FOR DESIGN AND DESIGN SPECIFICATIONS AND COSTS (Continued)

Case Study No.	Liner-Waste Compatibility Testing	Soil Permeability Testing	Regulatory Requirements	QA/QC Specifications	Cost
6	None (clay available on site)	Testing of in situ materials for site suitability and to develop basis for design	State discharge permit specified freeboard inspection and control, liner permeability, ground water monitoring, drainage and seismic design, and closure plans	NA	NA
7	None (clay available on site)	Testing of in situ materials to develop basis for design	State permits specified drainage controls, 3 ft of continuous clay material beneath pond, ground water monitoring, and submission of geotechnical, operation, and closure reports	Include pond excavation, compaction of clay, dike construction, soil properties testing	Gypsum pond: $910,000 (1973); expansion pond: $1,150,000 (1979)
8	Certain tests performed, but documentation not available	NA	None prior to establishment of ponds	NA	NA
9	None; FML selection based on compatibility data reported in the literature or supplied by the manufacturer	None	NRC license specified guidelines on site investigation, materials for construction, design, construction methods, and inspection/monitoring programs	NRC provided specifications for all soils related activities; no information available on FML specifications	NA

NA: No information available.

Limited cost data were available for SIs in Cases 1, 4 and 7. These costs vary widely reflecting differences in design, size, year of construction and the basis for the cost data.

4.2.3 Construction and QA/QC Inspection and Documentation (see Table 12)

Major deviations from the design specifications occurred only in Cases 8 and 9. In both cases failure to adhere to the design specifications and absence of adequate inspection to identify and document such deviations are responsible for subsequent failure.

No major problems were reportedly encountered during site construction in Cases 1, 5 and 6. No information was available on such problems (if any) encountered in Case 2, 3, 4 and 8. Some minor desiccation cracking of the clay liner observed during construction in Case 7 was eliminated by slowly raising the pond water level during start up.

The level of QA/QC inspection effort during construction including support tests and documentation of inspection and test results varied significantly. The effort was apparently most systematic and detailed in Case 5 where a total of 5,588 relative compaction tests and 147 in place permeability tests were performed during liner construction and the results recorded in "compacted fill" reports. Where the QA/QC program, or elements thereof (e.g., inspection of FML installation or testing of installed liner) was inadequate (e.g., in Cases 1, 4, 6, 8 and 9), system failure or poor performance requiring corrective measures resulted. Because of inadequate record keeping and poor or no documentation of inspection test results, major deviations from construction specifications which occurred in Cases 8 and 9 were not noticed in time for corrective measure.

4.2.4 Performance and Operating Results (see Table 13)

In cases for which sufficient operating data are available, the experience with FML systems has not been very satisfactory. Cracking and brittleness and seam separation have been documented for Cases 1, 4, 8 and 9. These liner failures have been attributed to deviations from design specifications, inadequate construction supervision and QA/QC inspection, and (in Case 9 and perhaps also in Case 1) failure to provide liner cover protection. Gas accumulation under the liner enhanced seam spreading in Case 4. Inadequate construction supervision and QA/QC inspection are also believed to be the causes of problems encountered with the clay liner and berm in Case 6.

Corrective measures taken or planned range from liner repair or replacement (Cases 1, 4, 8 and 9), construction of new embankment (Case 6), filling of sinkholes created by action of rainwater and grading to reduce rainwater ponding (Case 5), and limiting the height of the gypsum stack to improve stability (Case 7). The corrective measures taken were effective, at least in the short term, for all but Case 4 where leaks were again detected after liner repair. The inspection and maintenance programs generally include periodic visual inspection, and in Case 4, pond dredging.

TYPING GUIDE SHEET

TABLE 12. CONSTRUCTION AND QA/QC INSPECTION AND DOCUMENTATION

Case Study No.	Modifications/deviations from Original Design	Problems Encountered	QA/QC Inspection and Testing	Documentation/Record-keeping
1	NA	None reported	Owner inspection (no seam testing)	None
2	Recent installation of fiberglass protective liner cover and storage tank for liquid level control	NA	NA	None
3	Two lifts of clay material for levees of two ponds were thicker than specified due to unexpected soil property deviations	None reported	Random field density and moisture tests for levees; permeability testing of pond bases and levees sometime after all ponds began operations	Documentation of design and construction procedures for Site B ponds; no data for Site A ponds
4	FML used in addition to clay liner (original design); subsequently, EPDM-PVC substituted for CPE-PVC liner on cooling/evaporation ponds	NA	Permeability tests conducted on clay liners of evaporation/cooling ponds	None; vacuum testing of factory and field seams specified but not documented
5	None	Maintaining proper moisture content; thorough mixing and wetting of clay (at least 110% of optimum for compaction) alleviated this problem	Owner, geotechnical consultant, and state agencies closely scrutinized all phases of pond construction; a total of 5,588 relative compaction and 147 in place permeability tests conducted during liner construction	Compacted fill reports prepared for each pond recording inspection and test results
6	Minor field changes: bottoms of ponds 3 and 5 lowered 3 ft for more clay to build site	None reported	Geotechnical inspectors present during construction; permeability tests conducted on embankments	No documentation of observations or test results, only letters certifying that construction was done according to plans
7.	None	Some desiccation cracking due to long construction period; problems mitigated by slowly raising pond water level at startup	Geotechnical consultant inspected all construction activities; some in place density tests on dikes, Atterburg limits, and modified Proctor compaction tests	All inspection observations and tests documented in reports
8	Two major deviations: seaming overlap much less than specified and clay tiles used instead of perforated pipe and filter cloth in leak detection system	NA	NA	None
9	Seam connecting portions of Hypalon liner installed midslope on dike instead of in a ditch at the embankment toe as designed	Delays due to inclement weather	Inspection and testing of earthwork construction by consulting soils engineer, construction supervisor, dam safety inspector, NRC, and Army Corps of Engineers	Earthwork construction well documented; no data available on FML installation

NA: No information available.

PAGE NUMBER

EPA-287 (Cin.)
(4-70)

TABLE 13. PERFORMANCE AND OPERATING EXPERIENCE

Case Study No.	Liner System	Operating Difficulties/ Mitigation Measures	Adequacy/Reliability of Monitoring System	Inspection
1	Cracking and brittleness along slopes of the original DuPont 3110 polyolefin FML	Replacement of original liner with nylon-reinforced FML	Observed ground water contamination cannot be correlated with liner performance	NA
2	FMLs have performed well for approximately a two-year period	Storage tank recently installed to control liquid level in one pond	Substantial amount of data not yet available	NA
3	Analysis of limited ground water data is not conclusive regarding liner integrity	Seepage through an exterior dike of one pond due to its construction atop an old refuse fill was corrected with displacement fill	Wells were constructed at various times, and design data not available for all wells (apparent renumbering of the monitoring wells makes analysis of data difficult)	Monthly inspection of freeboard level, levee seepage or cracks, and observation of wildlife
4	PVC liner on bottoms of evaporation and cooling ponds have failed in the past and are currently leaking due to seaming failure; gas accumulation under liner and effluent discharge have compounded seam spreading; minor mechanical damage to EPDM on sideslopes	Repairs were made to both pond liners by draining and patching, gypsum was also added to plug leaks; all repairs were shortlived	Rapid detection of leakage by leak detection system	Monthly inspection of subdrain basins; cooling pond dredged every few years with mudcats
5	All clay lined ponds are performing satisfactorily	Sinkholes formed on slopes of pond 6. Ponded rainwater in contact with the dispersive clay (on the slopes) promoted piping of the clay and sinkhole formation; sinkholes were filled with gangue and ponding of rainwater was eliminated by grading	Based on field tests during construction, subdrain systems were properly designed and constructed; ground water monitoring wells are still being influenced by 3 abandoned, unlined ponds	Subdrain basins inspected monthly by owner, quarterly by the state
6.	Three documented instances of lateral waste migration underneath an embankment of pond 8 surfacing outside the pond	A new embankment keyed to firm unweathered clay constructed along the entire length of the old embankment has stopped the leakage	Substantial amount of data not yet available	Freeboard and embankments inspected monthly

(Continued)

TABLE 13. PERFORMANCE AND OPERATING EXPERIENCE (Continued)

Case Study No.	Liner System	Operating Difficulties/ Mitigation Measures	Adequacy/Reliability of Monitoring System	Inspection
7	All clay-lined ponds are performing satisfactorily	Landslides on the old gypsum stack; affected areas were graded and future stacking operations will incorporate new stack height limits	All wells strategically located and are operating satisfactorily	Weekly inspection of ponds and embankments; monthly inspection of piezometers and inclinometers
8	Seam separation, extensive swelling, and permeation of the EPDM liner resulted in failure	Thorough testing and assessment will precede the selection of a new FML replacement	Ground water monitoring system is not reliable due to the nature of ground water movement, tidal basin characteristics, and previously deposited wastes on site; clay/tile drains of the leak detection system are clogged	NA
9	Weak bonding, careless inspection, and poor maintenance have resulted in 4 instances of FML failure in less than 3 years.	FML properly repaired in each instance of failure; shoreline protection and rigorous inspection were recommended as long term corrective measures	Leak detection subdrains failed to detect substantial volume of leakage in places not directly over the subdrains; insufficient data available to assess the adequacy of the ground water monitoring systems	NA

NA: No data available.

As indicated previously in Table 9, Cases 2, 3, 4, 5, 8 and 9 employ some sort of leak detection systems; groundwater monitoring wells and programs have been established in all cases except Cases 2 and 4. The adequacy of the leak detection system has been demonstrated by in place tests in Case 5 and by actual operation in Case 4. The subdrain system in Case 8 was found to be plugged and ineffective due to deviations from specifications during construction whereby clay tiles had been substituted for the specified perforated pipes and filter cloth. The subdrain in Case 9 failed to detect a substantial volume leakage which occurred at places not directly over the subdrains. The observed ground water monitoring data collected to date have been inconclusive for Cases 1, 5 and 8 or insufficient for performance evaluation (Cases 3, 6 and 9).

As noted in Table 13, some sort of weekly or monthly inspection programs are in effect in Cases 2 through 7.

4.3 TECHNICAL ASSESSMENTS FOR INDIVIDUAL SITES

Detailed evaluation of the data compiled in reports for the nine cases studied resulted in the following assessments for individual sites.

4.3.1 Case Study No. 1

The two FML-lined hazardous waste SIs at this site were designed and constructed by the owner in 1972 and 1979. Since no regulatory requirements governed the design and construction of such facilities at the time, no geotechnical and hydrogeological studies, environmental impact analysis, or laboratory or field investigations preceded the actual design and construction to develop sound bases for siting, liner material selection, foundation preparation, liner installation, QA/QC inspection, etc. On site availability of land was the primary consideration for SI site selection. The 3110 polyolefin liners were installed without adequate or special foundation preparation and there were no documented QA/QC specifications or inspection of the completed liners. The liner selection was based on local availability and performance and compatibility data provided by the supplier.

Because of the above shortcomings, the ponds at this site have failed to provide satisfactory service. Visual inspection of the liner in the older pond indicated substantial cracking and brittleness along the embankment slopes. The liner in this pond had to be replaced. There is some evidence that the liners in both ponds are now leaking. Limited water quality data from monitoring and production wells indicate contamination of both the upper and lower aquifers, as evidenced by increases in the dissolved solids, sulfate, and nitrate concentrations. Because the data are limited and because there are multiple sources of potential contamination on and off site, the exact source of pollution cannot be ascertained. However, because underlying soils are highly permeable and due to the strong acidic nature and heavy metal content of the waste, any new liner failure could result in a substantial underground waste release and hence presents major potential for ground water contamination.

4.3.2 Case Study No. 2

The very satisfactory operation at this site indicates that (given proper site and wastewater characteristics) designing and constructing small ponds to provide satisfactory performance can be simple tasks.

Two very small (48 x 28 x 5 ft and 30 x 20 x 3 ft), relatively new, on site impoundments serve this pesticide formulation and packaging plant which generates intermittent discharges of wash-down and rinse wastewater. The waste volume is very small, seldom exceeding 400 gallons per discharge, two to three times per month. Ground water in the area is at 215 ft. The wash-down pond is lined with two layers of polyvinyl chloride (PVC) sheeting as the primary liner on both the bottom and the side slopes, and a 30-mil PVC as the secondary liner on the bottom only. The primary and secondary liners are separated by 1 ft of gravel. The rinse-water pond is lined with 20-mil chlorinated polyethylene (CPE) underlain with 1 ft of sand and a 10-mil PVC liner, with both liners extending along the bottom and the side slopes. The leak detection system for each pond is merely a single, perforated PVC pipe (a 3-in. pipe for the wash-down pond and a 1-in. pipe for the rinse-water ponds) extending halfway across the pond bottom and connecting to an observation well. A 1/4-in. fiberglass cover was recently placed over the primary liner in each pond for better protection against liner deterioration and damage during pond cleaning. A 20,000-gallon storage/equalization tank was also recently installed to control liquid level in the wash-down tank.

4.3.3 Case Study No. 3

This facility, which has impoundments located in two separate areas, is an example of the differences in performance between poorly planned and designed ponds and well-planned ponds. Problems resulting from poor planning cannot always be fully and permanently corrected through piecemeal remedies applied as the problems surface. This fact is illustrated by Site A, where nothing indicates that detailed site selection investigations or pond design took place. When the facility was investigated in 1971, wastes were seeping through pond levees that had been built on top of an old waste fill. Work was performed to correct the problem at that time, but seepage was reported again during investigations in 1978. At this time, specific levee permeability and thickness requirements were imposed, and the levees were rebuilt to conform to these requirements (5 ft. of clay with 10^{-8} cm/sec permeability or the equivalent). But leachate was discovered again in 1980, indicating that even the improved dikes were not able to prevent seepage.

In contrast to Site A, Site B was developed in 1971 with some effort to design ponds that would prevent waste migration. A site investigation was performed, and soil compaction and other design criteria were specified before construction. When the site was investigated in 1978, no seepage was reported, even though the levees did not all conform to the new permeability requirements and had to be modified.

Site A may not have been explicitly sited and designed to prevent waste seepage, though Site B was. This possibility appears to have been a significant factor in the performance of the facility with respect to seepage. Building Site A pond levees on a garbage foundation undoubtedly contributed to the seepage problem, and the displacement fill method of improving the dikes apparently was unable to solve the problem. Trench key work apparently did not provide a complete solution either, unless this leachate originated (as the facility owners contended) from an adjacent commercial landfill.

4.3.4 Case Study No. 4

The operating experience at this site illustrates (1) how the materials contained in the waste can provide an adequate barrier against further waste seepage under certain circumstances; (2) how liner failure and poor performance can result from deviations from desired liner specifications, reliance on liner-waste compatibility tests that poorly simulate actual field conditions, inadequate attention to geotechnical factors, and poor design and operating practices; and (3) how problems resulting from poor planning and design cannot always be permanently corrected through piecemeal remedies applied as the problems surface.

The major surface impoundment systems at this fertilizer manufacturing facility are 14-acre "gypsum" ponds, an 8-acre evaporation pond, and a 38-acre cooling pond. The gypsum ponds are unlined sedimentation ponds that have been used to recover gypsum for almost 20 years. The natural build up and solidification of gypsum in these ponds have rendered them impervious. This fact has been verified by actual examination and permeability testing of the core specimens from the bottom, which have indicated the presence of a very hard, low-permeability material.

The evaporation and cooling ponds, lined with EPDM on the slopes and PVC on the bottom, have failed in the past and are currently leaking. The liner specifications, which were written by the facility owner, called for a material that would not deteriorate when exposed to a waste with the following characteristics: pH of 2, maximum temperature of 110°F, 0.5% sulfuric acid, 1.63% phosphoric acid, 0.05% chlorides, 0.5% fluorides, and 1.0% organics. Though the available data indicate that the liner met the alkali and acid (pH 3.0) resistance tests, the material may not have been tested with a waste simulating the above characteristics. The actual liner manufacturer warranty also provides for an acid resistance of 1% weight change versus an original specification of 0.3% (both at pH 3.0) and limits the definition of organics to only five specific compounds, the total concentration of which is not to exceed 1%. Geotechnical and soil investigations had indicated that the native clay had a high content of calcium carbonate. This soil characteristic (which would lead to gas formation underneath the liner in the event of acidic waste leakage through the liner) was also not addressed in the site and liner design.

Liner bubbles have been observed in the FML-lined ponds. Inspections during repairs suggested seaming failure as the main initial cause of the liner leak. Seepage of the acidic waste into the underlying carbonate-bearing clay resulted in the production of large volumes of gas. Since no provisions had been made for venting, gas accumulation helped spread the seams and further aggravated the leaking. An overhead discharge pipe that diverted wastewater from the gypsum ponds to the evaporation pond was also an apparent contributor to the seam failure problem in the splash area. This problem was eliminated by installing a splash pad after the liner area was repaired. Liner repairs made in 1977 and 1979 by the original installer proved to be ineffective; monitoring data from the leak detection system indicate that both lined ponds have been leaking steadily since December 1979.

4.3.5 Case Study No. 5

This facility, containing eight clay-lined impoundments, demonstrates what can be achieved when the impoundments are well designed, constructed, and operated. The major reasons for the highly successful performance of these clay-lined ponds include: (1) the use of a very impermeable clay (which was available on site) as liner material, (2) the use of competent design, construction, and inspection contractors, (3) a conscientious owner/operator that closely scrutinized all phases of impoundment design, construction, and operation (from site selection to QA inspection), (4) extensive waste-liner permeability studies, (5) excellent QA/QC and record keeping during all phases of the project, and (6) good communication (input and feedback) between two different state regulatory agencies and all parties involved in the establishment of the ponds.

The performance of the impoundments is documented by many years of inspection reports and observation of the leak detection systems located beneath each pond. These leak detection systems were field-tested by state inspectors during construction. The good performance of the impoundment is not surprising, since the clay used to line these ponds has held the mineral deposits mined at this facility for centuries.

4.3.6 Case Study No. 6

The operating experience at this site illustrates how poor impoundment design and inadequate construction, inspection and record keeping can lead to leakage and poor performance. Wastewaters began seeping laterally out of one impoundment because (1) sand lenses within the natural clay were not identified and removed as specified in the design, and (2) at least one of the embankments was not adequately keyed into unweathered clay to prevent lateral waste migration.

This commercial hazardous waste disposal facility contains three 5-acre SIs lined with in situ clay (on the bottom) and recompacted clay embankments. Pond 8 receives geothermal and petroleum industry sludges and wastewaters, and the other two ponds are currently used for land treatment of organic sludges.

A soils investigation conducted before impoundment design indicated the presence of sand and silt lenses within the natural clay beneath the site. The design specifications called for (1) at least 2 ft of natural clay (with a permeability of 10^{-8} cm/sec) beneath the ponds in which no sand or silt lenses were discovered during pond excavation and construction and (2) subsequent placement of recompacted clay. The wastes began to migrate laterally along a sand lens underneath the embankment and surfaced outside the impoundment because: (1) all sand and silt lenses were not detected by boring tests or during excavation and construction, and (2) at least one embankment of Pond 8 was not keyed into the natural unweathered clay as specified (and this noncompliance with specifications was apparently not discovered and documented during QC inspection).

Though no seepage has been detected outside the other ponds, the other embankments at the site may not have been keyed into unweathered clay. The inspection and engineering certification reports for the site are very poor and unclear on this point.

4.3.7 Case Study No. 7

This facility is an example of how a combination of good site hydrogeology, proper design and construction, and adequate contingency planning can ensure satisfactory performance for surface impoundments located on in situ clay and diked with compacted clay. The very low permeability (10^{-8} cm/sec) of the in situ clay layer, which extends to a depth of 120 ft, and the high ground water table, which provides a reverse gradient and hence an added safety factor against waste exfiltration, are two important site characteristics contributing to the success of the impoundments at this facility which contains gypsum slurry and process wastewaters from a large fertilizer manufacturing operation. Monitoring of the deep ground water aquifer and over 9 years of monitoring data from a network of shallow wells have indicated no impacts on ground water quality or any seepage through sand/silt lenses.

The good performance of the clay-lined ponds can be attributed to the following design, supportive studies and construction provisions:

- Detailed geotechnical investigation of the site including extensive laboratory testing of boring samples of subsurface soil to develop a sound basis for design.
- Limiting borrow pit excavation within the pond areas to 5 ft below ground surface and 50 ft from dike bases. The former requirement will reduce the possibility of exposing silt/sand lenses whereas the latter will decrease the chances for the continuity of any silt/sand lenses which may go undetected.
- Removal of all exposed sand/silt lenses and subsequent compaction of a 3-foot layer of clay over these areas.
- Compacting clay in thin lifts to eliminate voids so as to meet permeability requirements.
- Comprehensive inspection and testing of pond and dike system construction.

- Installation of a network of shallow wells to monitor possible lateral seepage through sand/silt lenses.

Adequate contingency planning and preparedness of the work crew were instrumental in containing the impact of a recent failure of the 100-acre gypsum stack (in the gypsum "pond"). Upon noticing the signs for a possible failure onset, ditches which surround the pond were dammed off. Thus when the failure actually occurred, the nearly 6 million gallons of acidic water was totally contained. The failure of the gypsum stack has been attributed to the long term consolidation settlement of the underlying soft clay which caused tension cracking in the overburden gypsum stack and hence precipitated the failure. The magnitude of the time-dependent settlement of clay and the resistance of the gypsum stack to tension cracking had not been estimated correctly and allowed for in the original design.

4.3.8 Case Study No. 8

These two large EPDM-lined equalization and retention surface impoundments failed because of excessive swelling and permeation of the liner material and separation of the seams. The waste-liner incompatibility problem had not been predicted by the limited tests which preceded the liner material selection. Although there is not adequate record documenting the basis for liner selection, the selection of EPDM appears to have been based largely on its relatively low cost, ease of installation and ready availability. The seam separation problem is attributed to the deterioration of the glue used and failure to adhere to the requirement for minimum sheet overlaps called for in the design. Deviation from design specifications whereby clay tiles were substituted for perforated PVC pipes in the seepage drainage system also resulted in extensive plugging of the system and loss of capacity. Lack of adequate communication between owner and construction and installation contractors, inadequate inspection and acceptance procedures to ensure compliance with the recommended design, and assignment of a less than thorough/competent project engineer to the job are considered to be the major contributing factors to the facility failure.

The surface impoundments serve a chemical production plant located in an industrial coastal community. There has been continuous and considerable industrial activity in the area since 1900-1910, with changing plant ownerships, production operations, and waste disposal practices. Extensive on site disposal by present and past occupants has raised the ground surface elevation so that the current elevation at the SI site is about 20 to 30 feet higher than the original elevation. Because of this, it is almost impossible to assess the performance of SIs based on data from monitoring wells which indicate the presence of a range of chemicals, some known to be absent from the wastes currently impounded.

4.3.9 Case Study No. 9

This case study underscores the need for non-erosive shoreline protection at the waterline for FMLs in large surface impoundments located in areas experiencing very strong winds and severe winter conditions. While justifiably much emphasis was placed on engineering aspects of pond excavation and dike construction, not enough attention was directed to liner design and installation. Thus while there were thorough and documented inspections of the construction work, compaction testing and earthwork, there was limited QA/QC inspection of the liner installation and there are no records of any such inspections. While much has been learned about the stressful situations in severe climates, the experience illustrates the ineffectiveness of a piecemeal approach to correcting problems which reoccur at facilities with faulty or inadequate original design and construction.

This 62-acre uranium tailings pond is lined with 30-mil PVC on the bottom and 30-mil polyester reinforced Hypalon on the sides. No soil cover (or any other form of protective cover) was provided for the liner, presumably due to the fear that it would be very difficult to maintain such a soil cover in the face of the prevalence of very strong winds and hence large surface waves. There have been four investigated and extensively documented instances of the failure of the liner system in less than three years. The first failure occurred four months after installation and involved a 300-ft liner seam separation along the slope at the water line. Upon investigation it was found that the installer had deviated from design specifications. In an attempt to meet the construction deadline, the installation contractor had proceeded with the liner seaming task despite inclement weather and had not buried the Hypalon-to-Hypalon seam in a ditch near the pond bottom as specified.

Other failures include numerous punctures and tears due to or believed to have resulted from the following:

- a ruptured discharge line that was redesigned after the leak occurred
- carelessness during installation, e.g., dropping of sharp objects by work crews
- movement of foundation material that was not properly anchored and formed a ridge under the liner
- floating debris that was not removed after a severe winter storm damaged the support for a floating discharge line
- wave action against the ridge in the liner and the floating debris.

The leak detection underdrain system at this facility failed to detect a substantial volume of leaks which occurred at places not directly over the collection pipes.

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SECTION 5

OVERVIEW OF THE COLLECTED PROFESSIONAL OPINIONS

This section of the report, which is based on the individual interview reports presented in Section 7, is an overview of the professional opinions collected from technical experts, industry representatives, state regulatory agencies, etc., relating to various aspects of SI siting, design, construction, performance, R&D needs, etc. As noted in Section 3, the primary objective was to extend the previous data base to cover additional key individuals/organizations, with particular focus on the surface impoundment technology and identification of relevant R&D needs. A copy of the previous study containing reports on previous interviews was made available to each interviewee in advance of the interview. Many of the interviewees who had studied the report in some depth indicated that they had found the report very thorough and complete and that there was little additional material that they could contribute to the report. Also, because many of the factors affecting facility siting, design and performance are common to both SIs and landfills, the interview discussions covered both technologies. Some landfill-specific considerations which were covered are also included in the interview reports.

The overview presented in this section is primarily intended to provide insight as to the type and significance of the collected perspectives and is, by no means, a summary of all the material contained in the interview reports for which separate individual summaries are also included in Section 7. It should also be emphasized that the material presented here in this section and in the interview summary reports represents the professional opinions of the individuals interviewed. As would be expected in any survey of a diverse group of individuals representing a range of interests, there are some conflicts in the opinions expressed. These professional opinions are presented here without any change or discussion and no attempts have been made to analyze the views expressed or to present opposing viewpoints. Many of the opinions expressed, however, are substantiated by the case studies results discussed in Section 4.

For presentation purposes, the opinions and information collected are grouped and presented in this section under the following headings:

- Surface impoundments versus landfills
- Geotechnical and other considerations in siting, design and construction

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- Liner and cover systems design, construction and related topics
- Leachate collection system
- Leak detection system and ground water monitoring
- Research and development needs
- Regulatory considerations

5.1 SURFACE IMPOUNDMENTS VERSUS LANDFILLS

Except for some functional differences, which must be taken into account and addressed accordingly in the design, factors and considerations governing site selection, design, construction and monitoring are essentially the same for landfills and surface impoundments. SI-specific factors relate to liquid level fluctuations due to discharge, drawdown and wave action; freezing and thawing of free water available to clay; stresses under wastewater discharge points; continuous contact of liner with waste; and differences between the stresses on the bottom and on the side slopes. In clay-lined impoundments, liquid level fluctuations can present desiccation cracking of the side slope in dry weather. In certain above ground installations in Louisiana, the problem has been successfully addressed by lining the embankment slope with FML and firmly anchoring the toe below the permanent water line. The cracking has not been a problem in excavated facilities located in the ground water.

Surface impoundments are generally viewed as less permanent and more amenable to future corrective measures than landfills. In this regard, there is generally more design flexibility with SIs than with landfills.

5.2 GEOTECHNICAL AND OTHER CONSIDERATIONS IN SITING, DESIGN AND CONSTRUCTION

5.2.1 Siting Considerations

Siting in suitable geotechnical formations is generally considered to be the best protection and the first line of defense against ground water contamination, independent of whether or not the facility will be lined with clay, FML or other liner types. Reasoning that all liners may leak at some time, state regulations and guidelines thus place a greater emphasis on proper siting and relying on the waste attenuation capacity of soil than on newer liner technologies. The state of Louisiana, for example, requires extensive geotechnical studies in support of permit application for hazardous waste sites and has developed guidelines specifying number, depth, and spacing of borings and the type of data from borings which are needed to define hydrogeological settings. Similarly, approval of new sites in Ohio requires a preliminary geologic screening of candidate sites, a more detailed geotechnical investigation of the selected site, and submission and review of design specifications. The state of Colorado reportedly has developed geological survey maps of the state which assist facility developers and regulatory agencies in their geotechnical investigations for disposal facility siting (and other activities impacting groundwater and soil resources). These maps, however, serve only as initial guides in site screening and it remains the responsibility of the owner/operator to verify conditions at a particular site(s) when the selection is narrowed.

Under the proposed California regulations, new hazardous waste facilities must be located: 1) in continuous strata not less than 20 feet thick (having a permeability of $\leq 1 \times 10^{-7}$ cm/sec) that have natural or artificial barriers to prevent lateral waste migration; 2) outside of the 100-year floodplain, dam inundation areas, coastlines, and areas of rapid geologic change; 3) 200 feet from known Holocene faults; and 4) 5 feet above the highest anticipated elevation of the capillary fringe of underlying ground water to minimize leachate generation.

The state of Ohio considers the hydrogeological setting in much of the state very suitable for effective containment of hazardous wastes. In many areas there are 20 to 30 ft of native clay with permeability of 10^{-7} cm/sec or less. The low permeability and the depth of clay (which also provides significant waste absorptive capacity) are considered to provide adequate waste isolation and, hence, ground water protection. In areas where the ground water table is normally very high and close to the surface (e.g., in Louisiana) excavated facilities would be located in the ground water and this is considered by some designers to be the best means for waste containment and ground water protection. The high ground water table provides a positive pressure which prevents release and outward migration of leachate or waste in the event of the liner failure. This "intragradient design" approach, where the facility is intentionally located in the saturated zone, and the "hydraulic barrier design" concept, where an artificial piezometric pressure envelope is created between the primary and secondary liner, are actively promoted by Wehran Engineering (Middletown, NY) which claims excellent results in some large scale landfill applications of the intragradient principle.

Despite the recognition of the need for siting in suitable hydrogeological settings, availability of land on the premises is generally the basis for site selection for on site disposal. Site selection for off site facilities, however, has been more elaborate, involving preliminary assessment of potential candidate sites, screening of the more promising candidates and detailed feasibility and geotechnical studies. In addition to the technical criteria, political and social considerations are important considerations in selecting these sites since site selection rationale (especially for the larger sites) receive considerable scrutiny by the public and the regulatory agencies.

In addition to hydrogeological factors, the problem with odors is a major factor in siting and operating surface impoundments. Source control (i.e. not accepting odorous wastes or wastes which would react to produce malodorous compounds) remains the most effective operating method for controlling odors.

5.2.2 Development of Basis for Design

Geotechnical studies provide the basis for developing sound designs, ensuring use of suitable construction materials and practices, assessing seismic and other potential geologic hazards, and developing appropriate monitoring systems. The depth and thoroughness of a geotechnical investigation would vary with the nature and size of a project, design concept and applicable regulations.

A geotechnical study for developing the basis for design involves three steps: (1) a feasibility study or preliminary "look-over" to see if there are obvious reasons against siting in a particular location, (2) detailed evaluation involving borings inside and outside the area, and (3) data evaluation and recommendations for design modifications as necessary to mitigate problems identified (e.g., the occurrence of sand lenses requiring construction of cut-off walls).

Detailed and extensive geological investigations can be very costly and may fail to detect all major discontinuities in the soil. For example, a 100-ft wide buried old stream bed could be missed by test borings with 200-ft centers. Moreover, laboratory permeability test results for in situ materials are generally not very reliable because of the inadequacies and non-standardized nature of the test and the difficulty and cost of obtaining an adequate number of representative samples. Because of these limitations, geotechnical studies should always be supplemented by statistical data, analyses of soil boring/testing data, good inspection techniques during construction, and special design elements to mitigate peculiarities of site conditions.

5.2.3 Geotechnical and Related QA/QC Considerations In Site Construction

Geotechnical support should be a continuous effort covering not only site investigation and facility design but also the construction activities. Accordingly, it is very important that the geotechnical consultant's views be solicited in developing construction specifications and be incorporated in such specifications. Moreover, because the design firm can misinterpret the soils specifications, the geotechnical consultant should have an opportunity to review the final specifications. There are documented cases where problems later arose as a result of failure to give the geotechnical consultant an opportunity to review and input construction specifications.

Even with the soundest design, the adequacy of a completed facility cannot be guaranteed without assurance that the construction has been carried out per specifications. This underlines the importance of an effective construction QA/QC program. The key elements of such a program are thorough construction inspection, use of a competent inspector and detailed documentation and record keeping.

Thoroughness, conscientiousness and experience are desired qualifications for a field inspector. Inadequate construction inspection and verification are believed to have also been responsible for the failure or poor performance of certain major engineering projects, including many waste disposal sites (e.g., see Case Study Nos. 1, 6, and 8 reviewed in Sections 4 and 6). Although some major waste management companies have excellent in-house capabilities for writing construction specifications and for carrying out field inspections, as a matter of policy they use third parties for these tasks. One design company indicated that it usually will have its own inspector on the construction site. For example, it will have a geologist at the borrow pit to flag any problem which might be detected during excavation. Extensive testing (density, permeability, etc.) is also done on samples of soil from the liner during construction. The contractor is required to construct a test patch, before starting production work, using the equipment and techniques which are to be used on the full-scale job. Only when the test section meets the required specifications is the contractor allowed to proceed with the job.

Major surface impoundment and landfill jobs are usually done by reputable companies and also receive considerable public scrutiny. Because of their high visibility and the reputation of the companies involved, these projects generally incorporate comprehensive QA/QC programs covering all steps leading to the development of a completed installation. Cases of failure attributed to inadequate QA/QC, however, are more prevalent among the more numerous and scattered smaller jobs which are done by some less reputable, smaller companies. It is these installations which in totality present a much greater environmental threat than the much fewer, larger well-built facilities. (This consideration underlines the danger in any relaxation or wavering of the liability insurance requirements for jobs done by small business, as has been proposed and is now being actively pursued by certain interest groups.)

5.3 LINER AND COVER SYSTEMS DESIGN, CONSTRUCTION AND RELATED TOPICS

5.3.1 Clay Liner Design and Construction

The most critical factors in developing clay liners are compaction under proper moisture conditions, development of detailed construction specifications, construction supervision to ensure adherence to specifications, and reducing potential for desiccation cracking.

Clay compaction should be aimed at eliminating all air spaces and not necessarily at achieving a certain arbitrary compaction level as determined by the Proctor density test. Compaction wet of optimum is generally sufficient to ensure elimination of air spaces and development of a highly impermeable liner. Use of a specific compaction design criterion (high standard Proctor density) usually requires drying the clay and in so doing impermeability is endangered. Compaction tests were originally used for roadwork, dams and airstrips which require compaction studies to ensure strength and stability and are inadequate for design of liners which require permeability studies to ensure water-tightness. Since construction contractors generally follow specifications, which are in terms of the desired moisture content and density, it is the responsibility of the geotechnical firm to ensure that the density and moisture levels attained in the field are indeed consistent with the permeability goal per laboratory correlation tests.

The successful experience constructing low permeability clay liners in Louisiana can be duplicated in other regions of the country (including the arid zones) provided that (1) the clay is thoroughly mixed and particles greater than 1 in. are removed, and (b) adequate water is added to attain a uniform moisture content of 5% or more wet optimum. Maintaining adequate moisture may be an expensive proposition in arid regions, but may produce a system better than other available systems. Curing is very important in ensuring a uniform moisture distribution. Depending on the type of clay, 10 to 15 days may have to be allowed for curing in arid regions. To ensure proper curing, it is important that during the curing period the moisture level be closely controlled (i.e., more water added or moisture allowed to evaporate.

According to one geotechnical firm, compaction of the clay in the field should be carried out with a moisture content significantly above optimum (110% to 120% of the otpimum).

From a construction standpoint, clay soils are difficult to handle, spread, mix with water, place on slopes, and compact properly. Development of detailed specifications for handling the clay liner material and the use of an experienced and knowledgeable construction contractor are thus essential for obtaining the best possible representation of the clay liners as designed. Maintaining proper moisture content during field construction may be difficult under adverse weather conditions (e.g., prolonged wet periods) and this often requires exercise of good and on-the-spot judgement by the supervisory personnel. As an example, one particular job involved construction of a clay berm foundation and keying it to the bottom liner. But because of prolonged bad weather conditions, the facility owner chose to use a slurry well and get the project completed rather than wait for improvements in the weather.

As a QA/QC tool, field permeability measurement is an impractical means for assessment of the adequacy of the constuction techniques. The efficiency of the field operation is usually determined by measurement of density and moisture levels which have to be translated to permeability values using correlation curves developed in the laboratory for permeability versus moisture content/density. To constitute adequate representation of the field conditions, laboratory permeability tests should utilize actual waste and should be conducted under hydraulic gradients expected in the field. Since some clays will expand when not confined, thus gradually losing density and hence impermeability, changes in permeability over time versus density is an important clay property and should be measured in these laboratory tests.

Provided that adequate moisture content is maintained during and subsequent to construction, desiccation cracking should not be a problem with clay liners. It has not been a problem in Louisiana for excavated facilities because of the high water table, the construction method (which involves use of a relatively thick liner and compaction wet of optimum), and the practice of waste emplacement as soon as practicable. (As noted in Section 5.1, the cracking problem in above-ground facilities with fluctuating water surfaces has been successfully mitigated in Louisiana by use a protective FML cover). One design engineering firm considers cracking of clay a highly site-specific problem which depends on the type of clay and its silt content as well as the moisture level and construction technique. Their experience indicates cases where there have been only minor cracks even after one year of liner installation. In other cases, extensive cracks have been noted within a month of construction. Since liners are constructed in lifts and there is little chance for alignment of cracks in adjacent lifts, a limited number of shallow cracks which may go unnoticed during lift inspection should not present a major leakage problem.

5.3.2 FML Design and Installation

Selection of suitable liner material, use of proper installation procedures, rigorous QA/QC, and providing and maintaining protective cover for the liner are critical factors in ensuring a successful FML installation.

Selection of a specific liner material for a job is generally based on considerations of waste compatibility, cost, ease of installation and repair (given the particular size and configuration of the impoundments), maintenance requirements, and specific site conditions (e.g., potential damage due to traffic, animals, wind, precipitation, ground movement, and gas formation). Except for the waste compatibility factor, most commercial FMLs can meet these requirements when properly designed. High density polyethylene (HDPE), chlorinated polyethylene (CPE) and chlorosulfonated polyethylene (CSPE) are among the several liner types considered generally suitable for surface impoundment applications. In selecting a liner material, the designers generally rely on compatibility information available in the literature and/or obtainable from liner manufacturers and the performance experience in related applications (past projects). But when a satisfactory data base is not available, compatibility testing would be warranted.

Even though waste-liner compatibility tests can provide valuable data for selecting a suitable FML, a problem often encountered is that the characteristics of the actual waste which will come in contact with the liner is not known at the time of liner design and that the actual waste may have a different composition than that used in the compatibility testing. The difficulty of predicting future changes in waste characteristics (stemming from changes in plant operations/processes) so that such changes can be addressed in the design is a major reason for some cases of past liner failure after a few years of operation. For this reason, any time the character of the discharge stream to the surface impoundment is changed (physically or chemically) the compatibility with the liner system must be reviewed in detail.

Many experts argue that in general the issue of liner-waste compatibility has received an undue emphasis as evidenced by use of certain chemicals (e.g., pure acetone) in certain previous compatibility studies, which are totally unrepresentative of the leachate or liquid waste which will contact the liner. In the actual disposal environment, the leachate or the liquid waste is composed largely of water containing generally less than one percent impurities. One engineering firm, however, pointed out that the possibility of the liner coming in contact with concentrated organic waste should not be totally ruled out since under certain circumstances a leaking drum can conceivably release slugs of waste which may reach the liner.

Practical measures for mitigating the liner-waste incompatibility problems relate to good site design and operating practices and include waste segregation, pretreatment and banning disposal of certain troublesome wastes. A good landfill design would ensure "dryness" via adequate provisions for leachate removal and control of leachate formation through the use of properly designed, constructed and maintained caps. Thus, in this regard, the impermeability of the liner and its leachate containment capability are not relied upon entirely in developing adequate facilities. To minimize the amount of precipitation entering a landfill, one commercial hazardous waste management company is planning to use a temporary portable roof over a landfill during its construction and active life.

The concept of designing and operating landfills as "reaction vessels" whereby leachate formation and stabilization are intentionally promoted during the early life of the site (when the liner, in particular the FML, is still very new and presumably better capable of resisting the high strength leachate) might have some application to municipal landfills but not to hazardous waste landfills. Wastes placed in hazardous waste sites do not readily biodegrade and hence are not subject to rapid stabilization. Because of scheduling problems (at least in large commercial sites) it is difficult to arrange for co-disposal of certain wastes in the same cells as to achieve neutralization or controlled reactions.

In general, liner failure or damage resulting from waste incompatibility should be anticipated as being more prevalent where a large variety of waste materials are accepted, among smaller facilities where the owners/operators may not be fully aware of the incompatibility problems, and where there may be fewer receiving facilities and insufficient storage areas to segregate waste into a compatible containment environment. In this connection it is very important that site operators be provided with the documentation of the basis for liner selection and facility design so that he can pass judgement on compatibility of various waste loads before accepting them.

In addition to improper liner material selection and liner-waste incompatibility problems, poor field installation is considered to be a major cause of FML failure (see Case Study Nos. 4, 8, and 9). Field installation problems can be minimized in a number of ways, including the following:

- Minimizing field seaming where possible by use of larger liner sections whereby much of the seaming has been done in the fabricating plant where seams are produced under more controlled and favorable conditions and receive greater QA/QC attention.

- Providing good field supervision and appropriate technical assistance to the installer and use of an adequate QA/QC program.

- Use of experienced workers who will carry out the actual installation. The experience of the individuals who will be assigned to an installation task rather than that of the installing company per se is the important factor in ensuring high quality work. It is not uncommon that an installing company, selected for a job because of its extensive previous liner installation experience, assigned inexperienced crews and supervisors to the job and hence produced some inadequate products. Thus, in writing specifications and selecting installers, the emphasis should be on the experience of the individuals who will be committed to the job rather than on the experience of the company per se.

There is no practical solution to the common tendency of owners/operators to select low-bid installers who may not provide quality installations. In selecting contractors, one company has often by-passed the standard bidding procedure and has directly hired reputable contractors with a good previous track record.

According to one FML fabricator, liner connections to structures should not present a major design or installation problem, provided that the installation effort receives adequate QA/QC attention. Use of unreinforced material around connections is generally preferred as it can adequately withstand the normal expansion and contraction. This fabricator also believes that, contrary to what has been asserted, accidental or careless dropping of lighted cigarettes on the liner by workers during installation will not cause permanent damage to the liner. The liner material has generally a high ignition point and will not burn. It may temporarily soften slightly, but there will be no permanent damage.

Providing and maintaining protective cover for a liner is extremely important in preventing damage from the heat of the sun and minimizing problems stemming from vandalism, pinholes, chemical incompatibility, and wave action. (Case Study No. 9 presented in Section 7 and discussed in Section 4 is an excellent illustration of the value of the protective cover for liners subjected to severe stresses of the elements.)

5.3.3 Use of FMLs as Cover Systems

FMLs have been successfully used as cover systems in some large facilities. There have been no problems with erosion or slippage of soil cover, or failure with differential settlement in two such installations in California which were completed 4 and 6 years ago. In one of the facilities, the cover installation consisted of initial soil compaction, placement of a heavy (25-mil) polyethylene sheet, and placement of the soil cover. Natural vegetation growth has occurred in the soil cover at both sites. The owner's maintenance philosophy on both these sites has been to "keep an eye on them, but leave them alone". A slope of less than 3 to 5% and provisions to intercept and divert runoff from adjacent areas are critical to good cover maintenance.

5.3.4 Clay Versus FML

Many of those interviewed indicated that, other things assumed equal, they would prefer clay to FML for lining hazardous waste disposal sites.

These individuals believed that the current installation procedures cannot guarantee the integrity of the installed liners and that there are many documented cases of FML failures. Among the advantages claimed for clay over FML are the existence of considerable experience in working with clay, the relatively thick depth of the clay liner which also provides some capacity to absorb and attenuate waste, ready availability of suitable clay in many locations, and less susceptibility to damage during installation.

FML proponents indicate that, provided it is installed properly, FML would be preferred over clay for lining landfills or surface impoundments, primarily because of the much higher impermeability of FML. Permeabilities of less than 10^{-12} cm/sec for PVC and less than 10^{-14} cm/sec for Hypalon have been measured. In comparison, the permeability of typical recompacted clay is in the 10^{-8} to 10^{-7} cm/sec range. The importance of proper installation in achieving good performance is not only true for FMLs but also for other structures, even a steel tank which if installed improperly may leak.

Some designers prefer to use FML in conjunction with clay in a double liner system arrangement thereby taking advantage of the desirable properties of both liner types and compensating for the possible shortcomings of the individual systems. In all cases, however, the design calculations rely solely on clay as the protector assuming that the FML would not be available as a back-up system. One designer will use clay-only liners at locations where waste characteristics and hydrogeological conditions are suitable; FML-only liners, however, are not considered adequate for hazardous waste and will not be used if there is liner-waste incompatibility and the commonly encountered installation problems.

5.4 LEACHATE COLLECTION SYSTEM

Despite considerable improvements which have occurred in the recent past in leachate collection systems design and construction, apparent sporadic clogging of the underdrain systems remains a problem area. This, and not necessarily the occasional physical damage to the piping system which might occur during construction, is the major cause of the apparent leachate collection system failure. The newer designs use 4 ft diameter manholes which allow easier access to the piping system for cleaning and repair purposes. At the present time, however, there is no practical corrective measure for restoring the hydraulic capacity of a system when a sand and gravel drainage system is plugged. The potential for clogging can be reduced through proper design, source control, and QA/QC.

5.5 LEAK DETECTION AND GROUND WATER MONITORING SYSTEMS

Subdrain leak detection and ground water surveillance are two approaches used for monitoring the performance of liner systems. Subdrain leak detectors, which permit direct observation, have merits over monitoring wells or use of indirect methods (e.g., thermistor or resistivity devices). The advantages include: (1) rapid detection and timely warning of failure (e.g., in contrast to monitoring wells that detect leakage too late for proper corrective measure), (2) ability to monitor a relatively large area under the liner (~2% of the bottom) and not small areas around the perimeter, as with some indirect methods, and (3) yielding more reliable results than systems such as thermistors and resistivity devices which have not yet been fully tested in the field. Detection of fluid in the subdrain system can be interpreted to indicate the end of the service life for the facility. One limitation of the subdrain detection system, however, is that certain site conditions, such as a high water table may limit the system's usefulness. Another possible limitation may exist in using a subdrain leak detection system to monitor an impoundment lined only with a single flexible membrane liner in areas with highly permeable subsoils (see Case Study No. 9).

Unless the ground water monitoring system is tailored to the specific hydrogeological and other features of a site, it may prove inadequate in providing a true picture of the background conditions and changes in water quality. In many areas it would be very difficult to identify background "upgradient" and impacted "downgradient" ground water due to possible presence of isolated "pockets" of ground water underneath the sites or contamination from other sources (see Case Study Nos. 1 and 8). Ground water monitoring programs should thus be site- and situation-specific and should be for specific indicator parameters based on pond/leachate content, constituent mobility, test reliability, etc. Furthermore, sites with multiple disposal units should be designed so that the performance of individual units can be independently and continuously monitored and assessed using data from leachate/leak detection systems and ground water monitoring wells and water balance calculations.

5.6 RESEARCH AND DEVELOPMENT NEEDS

A very large number of research and development areas were identified by those interviewed. These areas, which relate to documentation and dissemination of design and operating experience and other relevant information, design analysis and development and evaluation of new design concepts, waste liner compatibility, and monitoring systems, are summarized below.

5.6.1 Documentation and Dissemination of Design and Operating Experience and Other Relevant Information

- A major problem in evaluating the performance of various designs and construction techniques is the lack of feedback from owners/operators after the facility has been placed in service. The absence of such feedback and the difficulty of obtaining operating data from full-scale facilities make it almost impossible to evaluate performance versus engineering design and construction practices used. What little performance data which have been analyzed in the literature have often been based on inaccurate or inadequate second-hand information. Case studies, such as those included in the present program which document the performance of hazardous waste management facilities (successes as well as failures), can yield valuable lessons and contribute to the development of better design and construction and operating procedures. These case studies should be extended to include additional facilities and the results should be made available to design engineers and regulatory agencies.

- In the waste disposal field, there is a considerable amount of accumulated experience (e.g., the optimum lift thickness versus construction equipment and clay characteristics in liner construction) which needs to be collected, analyzed and disseminated to practicing engineers and regulatory agencies.

- A comprehensive manual on seaming various types of FML should be prepared.

- There is a great need for independent verification of suppliers' claims as to the capabilities of various types of FML.

- A technical manual must be prepared that discusses in some detail how all of the elements of facility site selection, design, construction, operation, monitoring, maintenance and repair fit together.

- The effectiveness of various FMLs, seaming methods and QA/QC procedures for installation and seaming must be documented.

- State and federal agencies should be made more cognizant of the importance of construction inspection, certification, acceptance procedures, etc. in developing an adequate facility.

5.6.2 Design Analysis and Development and Evaluation of New Design Concepts

- The intragradient design for landfills and surface impoundments and the hydraulic barrier liner concept, which is considered especially suitable for surface impoundments, should be further investigated and its performance documented more elaborately.

- Studies must be undertaken to identify proper design, construction and operating practices which would minimize the potential for clogging of leachate collection systems for landfills, and to develop corrective measures for clogged systems.

- The effectiveness of various cover system designs in arid regions such as in California should be investigated.

- R&D effort should address development of laboratory procedures and practical field methods for obtaining clay liner permeability data for use in design. (Large field permeameters are not practical for clay soils with permeabilities $\leq 10^{-8}$ cm/sec).

5.6.3 Waste-Liner Compatibility

- Waste-liner compatibility must be assessed under realistic conditions and the results interpreted in terms of implication in full-scale facilities. Compatibility tests which have been reported in the literature have used chemicals (e.g., pure solvents) which are not representative of actual wastes which will be in contact with the liner. Furthermore, the reported degradation of a liner in a given test represents the effect on the very top surface layer and may be of little consequence to a thick liner. Results from laboratory studies must be verified under actual field conditions.

- Because waste stream constituent concentrations and the types of wastes handled may vary, practical and economic waste-liner compatibility tests, which can be used by facility operators as a means for accepting or rejecting incompatible waste loads, should be developed. In this connection, scientific basis must be established for identification and banning of troublesome wastes.

- Tools should be developed for predicting the characteristics of leachate expected from landfilling of various types of wastes for use in assessing compatibility.

5.6.4 Monitoring Systems

- A large number of landfills currently exist over usable ground water, some of which have failed and contaminated or present a contamination threat to ground water. There is a substantial need for developing protocols for early detection of site failure and corrective measure procedures.

- The national ground water monitoring program is inadequate in that the individual monitoring efforts have not been tailored to site- and waste-specific conditions (e.g., detection of contaminant species expected from a given facility). There is a substantial need for developing a technical basis and criteria for proper design of ground water monitoring systems with respect to number and location of monitoring wells and well depth.

- Studies should be conducted to develop the data base for assessing migration of fluids and attenuation of pollutants in partially saturated soils. Because of the lack of data in this area, current regulations are overly conservative in limiting the life of a surface impoundment to the time that it would take for the liquid to exit the bottom of the liner. In areas with low water tables, 5- to 10-ft zones beneath the liner would add extra life to the pond.

- Reliable, maintenance free, and retrofittable monitoring techniques for the unsaturated (vadose) zone must be developed.

- There is a great need for compilation and evaluation of data on mobility and persistence of various hazardous waste constituents in soils.

- There is a need for: 1) reliable and cost-effective methods for pinpointing the location of liner leaks; 2) repair techniques for leaking liners (especially for landfills), and 3) seaming (or bonding) methods for repair of FMLs that have been in contact with the waste and/or the elements for a number of years (i.e., bonding new and old, cured liner materials).

5.7 REGULATORY CONSIDERATIONS

The state of California, one of the three states with whom interview discussions were held in the present program, has drafted new and comprehensive hazardous waste regulations which represent substantial revisions to existing regulations. The proposed regulations include restructured waste categories, revised site classification criteria based primarily on geologic characteristics of each site, specific construction standards for containment and drainage control, comprehensive monitoring provisions, and separate provisions for mining and other non-hazardous wastes. The proposed regulations require double lining and use of FML in addition to siting in "Class I areas" for hazardous waste facilities, and are thus considered by some to represent an unnecessary "overkill". (A Class I area is defined as one providing "the optimum geological conditions for hazardous waste isolation, including natural geological barriers capable of preventing vertical waste movement from a waste management area to waters of the state".)

The state contends that the apparent "overstringency" of proposed California regulations is based on its experience which indicates that (1) some well designed facilities which have used the state-of-the-art technologies have failed, (2) geologic deposits are often discontinuous and the potential for lateral or vertical migration of wastes cannot be fully eliminated, and (3) when damage occurs, the cost of clean up can be very high. This apparent "overstringency" also reflects the state's desires to protect potential future uses of some of the state waters which may now be considered "unusable". The proposed regulations note that the requirement for use of FML in addition to clay is primarily to comply with the Interim Final RCRA regulations.

Because ground water monitoring systems historically have not been properly located or installed, the state does not know how well (or poorly) the hazardous waste facilities in California are performing. Accordingly, the proposed monitoring requirements are very stringent and detailed and include requirements for monitoring the unsaturated (vadose) zone. The proposed regulations also require biannual inspection of surface impoundment liners for detecting gross deterioration. Final regulations will probably also require provisions for liquid storage while the pond is being inspected. The proposed regulations also require a 3-ft freeboard allowance for surface impoundment.

As a result of recent changes in the state of Louisiana hazardous waste list (to conform to that of EPA) and the state's effort to discourage the use of impoundments for hazardous waste, there will probably be less than 50 impoundments under the state's control. In nearly all cases, these impoundments are used for treatment. Approval of new sites in Louisiana requires: (1) geotechnical information including data from borings on 200 foot centers to a depth at least 30 feet below proposed SI depth and definition of permeable zones and discontinuous lenses; (2) a synthetic liner plus three feet of clay with a permeability $\leq 10^{-7}$ cm/sec and (3) design data on liners, the leachate detection/ground water monitoring system operating plan, and drawings and construction specifications.

The state of Ohio approved 336 hazardous waste facility permits in 1981. Up to 55 of these facilities contain one or more surface impoundments each, and about 30 percent of them are used for disposal. Approximately one million ton of hazardous wastes were impounded in 1982. These facilities are generally older facilities which were placed in service at a time when regulations governing siting and design/construction of such sites were considerably less stringent than current RCRA requirements.

Under current procedures, approval of new sites in Ohio requires: (1) a preliminary geological screening of candidate sites, (2) more detailed geotechnical investigation of the selected site, (3) submission of detailed design specifications to the state, and (4) modifications to the plans as deemed necessary by the state.

Since the current Interim RCRA regulations require the use of liners, the state of Ohio regulations which are currently under development will also have to require use of such liners. Since federal regulations are usually not stringent enough for the state conditions, the state will continue to emphasize location factors and will require ground water monitoring even at double-lined facilities. Use of coupons to monitor liner conditions may also be required.

SECTION 6

CASE STUDY REPORTS

CASE STUDY NO. 1

1.0 GENERAL DESCRIPTION AND HISTORICAL BACKGROUND

Two on-site FML-lined SIs serve this electrolytic metal refining plant located in a semi-arid to desert area of the Southwest. The plant originally started operation in 1928 and underwent modernization and expansion in 1942 and 1967. A "small" SI and a "large" SI are used for storage and disposal of process wastes and were placed in service in 1972 and 1979, respectively. In addition to the two FML-lined SIs, there are a series of interconnected bentonite-lined ponds for disposal of cooling tower blowdown and furnace cooling water as well as a drain field for septic tanks handling the plant's sanitary waste. The plant is located in a heavily industrialized region with several major hazardous waste generators adjacent to the plant site.

Prior to 1972, the process wastes were discharged into an unlined 100 x 200 x 4 feet pond which, because of leakage, was filled and abandoned in 1972. A lined facility (20 x 50 x 6 feet) was then constructed, but was soon after taken out of service when the present small SI became operational. Figure 1 is a diagram of the facility layout.

2.0 BASIS FOR SITE SELECTION

The SIs were located on site because of land availability. Within the plant boundaries, the soil condition is generally the same (sandy upper soil with underlying colligie clay) with the soil surface about 80 feet above the ground water table. The specific locations of the SIs within the facility were thus of no concern in site selection. No environmental impact assessment was required or performed in connection with siting.

3.0 DESIGN, CONSTRUCTION AND INSTALLATION FIRMS UTILIZED

The SIs were designed and constructed by the owner using contract labor. A consulting firm was responsible for the installation of the ground water monitoring system in 1982.

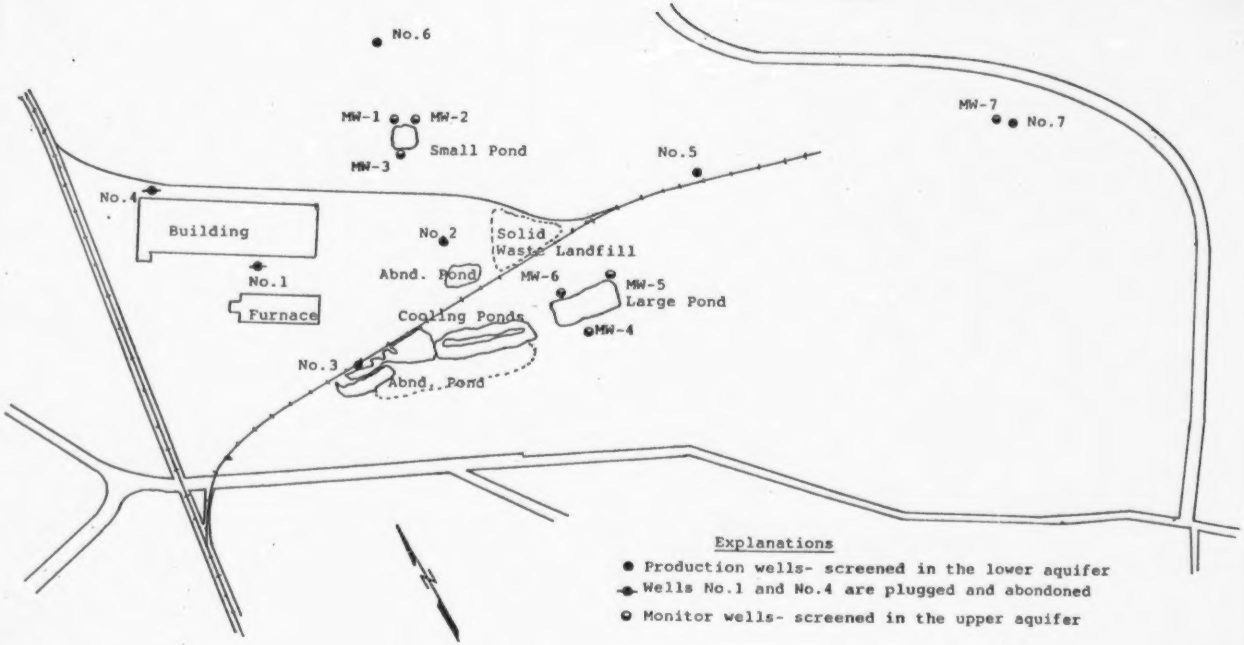
No.6
MW-1
MW-2
Small Pond
MW-3
No.5
MW-7
No.7
No.4
Building
No.1
Furnace
No.2
Abnd. Pond
Solid Waste Landfill
MW-6
MW-5
Large Pond
MW-4
Cooling Ponds
No.3
Abnd. Pond
N
Explanations
● Production wells- screened in the lower aquifer
Wells No.1 and No.4 are plugged and abondoned
○ Monitor wells- screened in the upper aquifer

Figure 1. Facility Layout

4.0 DESIGN CRITERIA

4.1 Purpose of the Impoundments

The purpose of all SIs at this site is storage and ultimate disposal of impounded waste via evaporation.

4.2 Waste Characteristics

Aqueous acidic waste (pH typically less than 2) discharged to the FML-lined SIs consists of process liquor and sludge high in heavy metals content. Total waste volume discharged to these SIs in 1982 was 843,750 gallons (see Tables 14 and 15).

Analysis of waste water in the evaporation ponds is shown in Table 16.

4.3 Service Life

Although the FML manufacturer has warranted the liner material for a period of twenty years for both SIs, no specific service life for these SIs is given in the design. No data are available on the service lives of the evaporation (bentonite-lined) ponds. With the current plant modernization program which involves in-plant process changes, significant reduction in volume and strength of waste is anticipated, and this should extend the service life of the facility.

TABLE 14. HEAVY METALS ANALYSIS OF SLUDGE FROM THE "SMALL" SI

(Sampled 6/16/81)

Ag	0.009 %
As	0.20 %
Pb	0.09 %
Se	0.008 %
Ba	ND
Hg	ND
Cd	ND
Cr	0.0005%

TABLE 15. ANALYSIS OF SI WASTE*

Constituents/ Parameters	Date Sampled			
	1960 Large SI	6/82 Large SI	1960 Small SI	6/82 Small SI
Ca	200	660	250	250
Mg	200	350	100	180
Na	800	5200	500	910
K	-	180	-	77
HCO_3	0	0	0	0
Cl	50	500	50	66
SO_4	128042	192000	20157	33200
NO_3	-	3630	-	181
F	-	0.33	-	0.21
Free H_2SO_4	10400	-	5200	-
As	40	59	40	15
Be	-	<1	-	<1
Te	10	-	280	-
Cd	-	2.2	-	1.5
Cr(VI)	ND	<0.1	ND	<0.1
Cu	1700	10600	5010	13000
Fe	60,000	11,500	1,000	10,000
Pb	5	4.77	2	3.30
Mn	100	400	2	-
Hg	-	0.004	-	0.004
Ni	7400	-	2000	-
Se	<1	0.005	<1	0.003
Ag	ND	0.016	ND	-
Zn	-	-	-	-
Co	30	-	1	-
Sb	50	-	4	-
Bi	5	-	2	-
ALK	0	-	0	-
pH	1.9	1.6	2.4	1.76
Phenols	-	<0.001	-	<0.001
Specific Conductance	61700	49000	22600	41000
TOC	-	<1	-	<1
TOX	-	9.6	-	3.3
TDS	-	296000	-	196000

*All units are mg/liter, except Specific Conductance (micromhos) and pH (Standard Units).

TABLE 16. ANALYSIS OF COOLING PONDS CONTENT*

Constituents/ Parameters	Date Sampled			
	5/69	5/72	2/75	2/76
HCO_3	134	-	-	-
Cl	346	305	245	122
SO_4	168	154	156	295
NO_3	-	-	-	214
As	-	<0.01	-	-
Be	<0.05	<0.04	-	-
Cd	-	<0.001	-	-
Cr(VI)	-	<0.004	-	-
Cu	-	0.26	-	-
Pb	-	0.004	-	-
Mn	-	0.067	-	-
Hg	-	<0.005	-	-
Ni	-	0.09	-	-
Se	-	<0.02	-	-
Ag	-	<0.001	-	-
Zn	-	0.1	-	-
pH	8.7	-	9.1	9.3
Specific Conductance	1672	1098	1494	1840

*All units are mg/liter, except Specific Conductance (micromhos) and pH (Standard Units).

Analysis is average of 5 grab samples.

4.4 Site Hydrogeology

No hydrogeological studies were performed prior to SI construction to develop basis for design. The 1982 hydrogeological study indicated the following(1):

Evaporation rate: 7.8 ft/yr.

Rainfall: 0.73 ft/yr.

Depth to ground water: in excess of 70 ft.

Mean average annual temperature range: 44°F to 83°F (69°F average).

Ground water conditions: The regional ground water system, part of which underlies the facility, is a complex, tripartite system, composed of two separate but interacting aquifers, and an overlying source of recharge/discharge. The upper aquifer is a water-table aquifer and the underlying aquifer is under semi-confined conditions.

For more than forty years, the upper aquifer has been recharging the underlying aquifer, beneath a nearby metroplex, at a steadily increasing rate. This is the result of increasing pumpage, in excess of recharge from the lower aquifer, and subsequent potentiometric surface declines. The river is discharging to the upper aquifer in increasing quantities, except in one area where this discharge has been cut off by engineering modifications to the river course.

The volume of fresh water in the lower aquifer, the principal source of municipal and industrial water in the area, is being depleted at an increasing rate. Naturally poorer quality water from within the lower aquifer and recharge from the upper aquifer is partially replacing it. The quality of the natural recharge from the upper aquifer is having an increasingly adverse effect on the quality of water in the lower aquifer. Quality impact on the upper aquifer, whether natural or man-made, has the potential of in turn affecting the lower aquifer.

There are seven production deep water supply wells on the premise (see Figure 1). Two of the wells have been plugged and abandoned due to water quality deterioration; the remaining five wells are active.

4.5 Waste-Liner Compatibility

No waste-liner compatibility testing was required or performed. The selection of the specific liners was based on local availability and reported successful use in other locations (based on information provided by the supplier and the owner's experience).

4.6 Soil Permeability

No soil permeability tests were performed prior to SI design. The 1982 hydrogeological study provides the following description of the underlying soil (1):

> Soil beneath and adjacent to the site is a mixed thermic, typic torripsamment, entisol. The soils are dominantly well drained, highly permeable (0.44×10^{-2} to 1.4×10^{-2} cm/sec), moderately alkaline, loamy fine sand. They have low available moisture (0.08 in./in.) and low shrink-swell potential. They form profiles commonly over 60 inches thick. They are unsuited for most agricultural uses and readily subject to wind erosion. Within much of the plant proper, soil characteristics have been modified by excavation, filling, compaction, and burial.

From the above-referenced study, the hydrogeologic consultant concludes that there exists a low potential for migration of hazardous waste constituents (heavy metals) based on the unsaturated zone characteristics of the geological materials lying between the pond and the aquifer, and the expected changes in waste characteristics as it migrates through the soil (2). The following qualitative reasoning is provided (2):

> In excess of 70 feet of partially saturated sand and clay sediments underlie each pond. Although the permeability of these units are not sufficiently low to mitigate significant quantities of seepage, they do offer a significant thickness of soil matrix in which hazardous waste constituents within the ponds can be attenuated. The hazardous waste constituents within the pond are represented entirely by metals including arsenic, nickel, and copper. Although the wastewater within the pond is discharged to the pond at a pH typically less than two, the pH would change significantly, i.e., less than 2 to approximately 8 in migrating to the water table. This increase in pH would tend to precipitate metals within the wastewater. In addition to pH change within the wastewater, the soil environment is slightly alkaline and will promote formation of immobile carbonates and hydroxides. The partially saturated conditions of these soils also result in an oxidizing environment further favoring attenuation of all major metal species including arsenic.
>
> Therefore, based on a consideration of the characteristics of the partially saturated soils and the specific hazardous waste components within the facility, i.e., metals and pH, it can be concluded that there would exist a low potential for migration of these constituents through the >70 feet of partially saturated soil.
>
> The low potential for migration of metals is physically demonstrated by the fact that prior to synthetically lining the wastewater ponds in 1972, migration of liquids from these ponds had occurred as represented by indications of ionic impact in groundwater samples obtained from monitor wells adjacent to the ponds. However, no concentrations of metals were found within the groundwater samples, thereby supporting the concept that the partially saturated soils should attenuate and mitigate migration of these hazardous waste constituents.

4.7 Regulatory and Permit Requirements

At the time that the FML-lined SIs were designed and constructed (1972 and 1979), there were no specific regulatory and permit requirements for design and construction of the facility. Late in 1981, the state, however, notified the owner of the following requirements for ground water monitoring (3):

> Effective November 19, 1981, the owner or operator must implement a ground water monitoring program capable of determining the facility's impact on the quality of ground water in the uppermost aquifer underlying the facility. The owner or operator must keep records of the analyses performed at each well throughout the active life of the

facility and throughout the post-closure care period as well. Additionally, during the first year of operation, reports must be submitted to the state for each ground water monitoring well within 15 days after completing each quarterly analysis for the parameters listed.

4.8 Cost Considerations

No data are available on consideration of costs as criteria in design (e.g., liner or contractor selection).

5.0 DESCRIPTION OF DESIGN AND DESIGN SPECIFICATIONS

No information is available on the design of the bentonite-lined evaporation ponds.

5.1 Dimensions and Configurations (See Figure 1 for relative locations.)

Small SI: 125' x 125' x 7'.

Large SI: 280' x 170' x 5'.

SIs are designed for operation with a 2-feet freeboard.

5.2 Foundation Preparation, Leak Detection System, and Backfilling

No special foundation preparation was utilized prior to placement of the FMLs as the owner felt that the ground surface was suitable to receive the liner. When the small SI was relined, six feet of compacted clay was placed as a liner foundation. There are no leak detection systems underneath

5.3 Liner

The small pond was originally lined in 1972 with a 20-mil DuPont 3110 polyolefin FML. This original liner, however, deteriorated (apparently due to UV oxidation) and was replaced in 1981 with a B.F. Goodrich 30-mil HP-6 nylon-reinforced FML. The larger SI is also lined with the 3110 polyolefin material. The liners are anchored in gravel trenches along the edge. Liner installation was carried out by a contractor, apparently using the procedures recommended by the liner suppliers (i.e., DuPont and B.F. Goodrich). The seaming of the HP-6 FML, which was done via manually-applied cement adhesive, was supervised by B.F. Goodrich. Seaming of the 3110 liners was done using a heating machine.

5.4 Inlet/Outlet and Other Structures and Provisions

An 8-inch diameter pipe delivers waste to each SI. Since SIs serve as evaporation ponds, there is no outlet pipe for the ponds. Aeration to increase evaporation rate was attempted at one time, but was discontinued to avoid acid drift. Both FML-lined SIs are fenced and warning signs are posted to keep away unauthorized personnel. With the exception of an occasional landing of birds in the pond, the fence has been effective in keeping away wild animals.

5.5 Ground Water Monitoring

In May of 1982, seven monitor wells were installed into the "upper" aquifer beneath the facility (see Figure 1 for locations). The stratigraphy encountered while drilling the wells was predominantly fine to coarse sand with minor amounts of clay and silt. A few thin clay layers were penetrated. Locally, sandy gravel and cobbles (up to 5 inches) were encountered. These wells are screened in the upper aquifer. The depths to water table in wells 1 through 7, measured in May 1982, were 126.7, 121.5, 123.8, 72.0, 82.4, 81.1, and 115.0 feet, respectively.

5.6 Quality Assurance and Quality Control Specifications

There were no rigorous specifications and requirements for QA/QC in connection with securing and installing liners. The owner's personnel who inspected the construction and installation activities reported "no problems". There were no written specifications for testing seams or the integrity of the installed liner.

6.0 DEVIATIONS FROM DESIGN, PROBLEMS ENCOUNTERED DURING CONSTRUCTION, AND COSTS

Because of the simplicity of the design and construction, and the fact that they were carried out by the owner itself, there were apparently no modifications to the original plans, or if there were any modifications, they were not documented. There were apparently no major problems encountered during the construction.

The following are estimates of costs incurred by the owner:

- Initial construction
  - Small SI - $15,000 to $20,000 (1972)
  - Large SI - $56,000 (1979)
- Relining of small SI - $26,000 (1981)

7.0 PERFORMANCE DATA AND OPERATING EXPERIENCE

7.1 Liner Performance

As noted in Section 5.3, the original 3110 liner in the small SI was replaced by a new nylon-reinforced Goodrich HP-6 FML, nine years after initial lining. Visual inspection of the 3110 liner indicated substantial deterioration (cracking and brittleness) along the edges. Since the water level in the pond fluctuated and, at times, rose above the visible cracks, a state regulatory official who visited the site during a semi-annual inspection recommended that the liner be replaced. The owner attributes the deterioration to UV attack. Similar extensive deterioration has not yet been detected in the 3110 liner in the large SI because of its younger age (4 years). No other data, except visual inspection reports on the condition of the exposed liner along the edges, are available for either this 3110 liner or the Goodrich HP-6 FML to assess liner performance and conditions.

7.2 Monitoring Data

Sampling and analysis of the monitoring wells is only a recent activity and a substantial amount of data is not available to assess the full impact of site waste disposal activities on ground water. Because of the multiple source of contamination (present and past), the exact source of pollution (e.g., possible loss of liner integrity in one or both of the SIs) cannot be ascertained. Based on the very limited water quality data from the on-site monitoring and production wells and the equally limited historical data on changes and trends in the background water quality in the upper aquifer (especially with respect to some of the critical waste constituents), a hydrogeologic report prepared by a consultant (1) presents the following analysis and conclusions:

> The quality of water from the monitor wells and production wells is listed in Table 17. Based on water quality, the monitor wells are divisible into three groups: those around the small pond (MW-1,2,3), those around the large pond (MW-4,5,6), and the background well (MW-7) - see Figure 1. The quality of water from MW-7 is comparable in all respects to areal water quality in the upper aquifer (see Table 18).
>
> Water from MW-1, 2 and 3 is similar to the background water in the upper aquifer in terms of relative concentrations of major constituents. However, the average total dissolved solids concentration of these wells is slightly higher than that of nearby background water (Table 18) and they also have elevated sulfate and nitrate concentrations (Table 17). These higher TDS, NO_3, and SO_4 concentrations in waters from MW-1, 2, and 3 can be attributed to one or more of three sources.
>
> - First, an indeterminate amount of leakage from the small pond occurred in the mid-to-late 70's while the pond liner was in a deteriorated condition.
>
> - Second, an indeterminate amount of leakage from the abandoned, unlined pond near Production Well 2 may have impacted the upper aquifer and since migrated laterally to the extent that it is now detectable beneath the current small pond. Quality of discharge to this abandoned pond was similar to that currently discharged to the small pond.
>
> - Third, leakage from evaporation ponds located at an adjacent facility may have impacted the upper aquifer to the extent that this leakage is now detectable beneath the small pond. Analyses of water

TABLE 17. ANALYSES OF WATER FROM MONITORING WELLS (MW) AND PRODUCTION WELLS (PW)

Well	Date Sampled	Ca	Mg	Na	K	HCO_3	Cl	SO_4	NO_3	F	CO_3	As	Ba	Cd	Cr	Cu
MW-1	6/15/82	199	71	410	29.8	634	350	690	41.6	1.13	0	0.001	<1	0.08	<0.05	0.05
MW-2	6/15/82	400	119	540	38.3	476	340	1530	44.7	0.75	0	0.001	<1	0.03	<0.05	<0.05
MW-3	6/15/82	184	53	430	25.9	464	420	560	20.8	0.97	0	0.003	<1	0.04	0.08	<0.05
MW-4	6/15/82	68	25	360	13.5	293	430	240	4.3	1.13	6	0.003	<1	0.02	<0.05	<0.05
MW-5	6/15/82	72	24	380	12.1	200	490	200	2.3	0.66	0	0.007	<1	0.02	<0.05	<0.05
MW-6	6/15/82	82	23	380	10.7	207	550	180	1.9	0.53	0	0.007	<1	<0.01	<0.05	<0.05
MW-7	6/15/82	93	33	320	16.3	281	380	340	5.3	0.73	0	0.005	<1	0.02	<0.05	<0.05
PW-3	6/17/82	40	12	140	5.7	134	230	70	2.3	0.64			<1	0.02	<0.05	
PW-4	6/12/56	25	6	138		162	93	80		0.7						
PW-4	7/20/69	63	19	180		142	300	81	0.7	0.7						
PW-5	6/12/59	22	7	106		160	64	85	2.2	0.7						
PW-5	5/15/75	50	16			184	150	120								
PW-5	6/28/76	51	18			177	178	153								
PW-5	1/09/78	43	16			160	160	110								
PW-5	1/18/79	54	17	146		167	188	115		0.54			0.11	<0.01	<0.05	<0.1
PW-5	12/30/80	54	17	148		160	195	115	<4.4	0.50						
PW-6	6/28/76	44	16			154	205	115								
PW-6	1/09/78	50	17			150	230	100								
PW-6	9/25/79		22	250	36	154	265	106	3.5							<0.01
PW-6	6/16/82	82	29	160	14.6	146	390	100	6.2	0.52			<1	0.02	<0.05	<0.05
PW-7	6/28/76	34	9			129	123	108								<0.01
PW-7	3/30/77	38	10	120	12	130	140	86	2.9	0.6						

(Continued)

TABLE 17. ANALYSES OF WATER FROM MONITORING WELLS (MW) AND PRODUCTION WELLS (PW) (Continued)

Well	Date Sampled	Fe	Pb	Mn	Hg	Se	Ag	Total ALK	pH	Phenols	Spec Cond.	TOC*	TDS	TOX*	Pesticide†
MW-1	6/15/82	<.05	.05	.08	<.001	<.001	<.01	520	8.00	.005	3300	6.2	2151	2.9	<.002
MW-2	6/15/82	<.05	.05	1.47	<.001	<.001	<.01	390	8.03	.001	4500	6.5	3264	1.0	<.002
MW-3	6/15/82	.10	.05	<.01	<.001	<.001	<.01	380	8.04	.004	3000	5.0	1929	0.5	<.002
MW-4	6/15/82	<.05	.05	.42	<.001	<.001	<.01	250	8.51	.002	2400	6.7	1292	3.9	<.002
MW-5	6/15/82	.05	.05	.60	<.001	<.001	<.01	164	8.22	<.001	2300	5.6	1279	1.1	<.002
MW-6	6/15/82	<.05	<.05	1.17	<.001	<.001	<.01	170	8.25	.005	2400	7.9	1329	2.6	<.002
MW-7	6/15/82	<.05	<.05	.33	<.001	<.001	<.01	230	8.28	<.001	2300	6.1	1330	0.4	<.002
PW-3	6/17/82	<.05	<.05	<.01			<.01		8.30		1200		566		
PW-4	6/12/56	.1						139	8.35				476		
PW-4	7/20/69								7.2		1340		745		
PW-5	6/12/59								7.8		639		397		
PW-5	5/15/75								7.8		1050				
PW-5	6/28/76								8.2		1180		684		
PW-5	1/09/78								7.8		991				
PW-5	1/18/79	.13	<.05	.01			.01	137	7.9		1040		630		
PW-5	12/30/80	<.1		<.01				131	7.8		1070		640		
PW-6	6/28/76								8.3		1180				
PW-6	1/09/78								7.8		1160				
PW-6	9/25/79	.29		.04					7.2				809		
PW-6	6/16/82	<.05	<.05	.05			<.01	120	8.15		1700		720		
PW-7	6/28/76								8.4		825		488		
PW-7	3/30/77	.01							8.1				508		

All units are mg/liter except Specific Conductance (micromhos) and pH (Standard Units).

*Indicated Total Organic Carbon (TOC) and Total Organic Halogens (TOX) values are arithmetic mean of 4 replicate analyses.

†Pesticides analyzed for are Endrin, Lindane, Methoxychlor, Toxaphene, 2,4-D, and 2,4,5-TP (Silvex).

TABLE 18. STATISTICAL PARAMETERS OF GROUND WATER QUALITY DATA IN THE VICINITY OF THE FACILITY

Wells	n	Range	Mean	Std. Dev.
Chloride				
Lower Aquifer*	17	51-385	179	93
Production Wells 3, 5, 6, 7	6	123-390	211	88
Upper Aquifer†	13	135-990	394	244
Monitor Wells‡	7	340-550	367	151
Fluoride				
Lower Aquifer	17	0.37-0.80	0.64	0.11
Production Wells 3, 6, 7	3	0.52-0.64	0.59	0.05
Upper Aquifer	13	0.28-1.40	0.69	0.30
Monitor Wells	7	0.53-1.13	0.84	0.22
Total Dissolved Solids (TDS)				
Upper Aquifer	14	432-2760	1551	710
Monitor Wells	7	1292-3264	1816	669
MW-1, 2, 3 (around small SI)	3	1929-3264	2448	-
MW-4, 5, 6 (around large SI)	3	1292-1414	1345	-
MW-7 (background)	1	-	1330	-

*Samples from lower aquifer wells in the general area collected during 1976 - 1982 period.

†Samples from upper aquifer wells in the general area collected during 1972 - 1981 period.

‡On-site monitor wells and production wells sampled during June 1982.

All concentrations in milligrams per liter.

from these evaporation ponds show high concentrations of SO_4, NO_3, and TDS.

It is not possible to quantify the relative effects of each of these sources on the upper aquifer waters intersected by MW-1, 2, and 3. However, in view of distances and water table gradient, the first and second potential leakage sources are more likely the sources of the high SO_4, NO_3, and TDS concentrations in the shallow ground water beneath the small pond.

Water levels in the monitor wells adjacent to the large pond (Well Nos. 4, 5, and 6) indicate a slight mound atop the regional upper aquifer water table beneath the facility. As the large pond is only 3 years old, and synthetically lined, and has probably not leaked, this mound is probably the result of leakage from the cooling ponds which, due to their size and age, offer more potential for leakage to the aquifer. The water level in MW-2 indicates a slight irregularity in the water table of uncertain origin. It may be associated with the cooling pond mound, or past leakage from the small pond or other ponds, or the result of lithologic discontinuity in the aquifer. Overall, water levels in the monitor wells indicate a water table gradient to the northeast.

The quality of water from MW-4, 5, and 6 is similar to lower aquifer water in terms of relative concentrations of major constituents. However, the TDS concentrations in water from these monitor wells is about 1.5 to 3 times the concentrations in lower aquifer water. Also, the relative concentration of Ca and Mg, with respect to Na+K, is slightly less (15 - 20% versus 20 - 30%) in the monitor wells than in wells producing from the lower aquifer. The overall similarity is evidence of leakage from the cooling ponds impacting the shallow ground water. Since lower aquifer tapping wells supply water for plant processes and cooling, some of which is discharged to the cooling ponds, water in and leaked from the ponds should be similar in quality to lower aquifer water. However, process and pond evaporation increases the absolute concentration of dissolved constituents. The slight decrease in Ca and Mg concentrations with respect to Na+K is probably due to discharge to the cooling ponds of softened boiler feed water. Though impact by cooling pond leakage is evidenced in MW-4, 5, and 6, the impact cannot be considered adverse since there is no decrease in aquifer water quality. The quality of water from these wells is intermediate beneath upper and lower aquifers water quality.

With respect to trace metals, none of the monitor wells indicated concentrations which would be indicative of impact from the ponds. The concentrations of cadmium (Cd) and manganese (Mn) found in the monitor wells may be indicative of regional quality, however, there is little regional background data for these constituents.

MISCELLANEOUS

In October 1982, the owner requested from the state regulatory agency a waiver from full interim status ground water monitoring requirements under RCRA, based upon results obtained from their initial quarterly sampling and analysis program performed in June 1982. This request, which suggested replacement of the full sampling and analysis protocol (which includes analyses for pesticide and other species) with a partial protocol emphasizing heavy metals and ionic species, was denied by the state regulatory agency in late 1982. Recently, a full semi-annual protocol was completed by the facility. Since the results of this recent monitoring effort were found to be identical to those of the first quarterly effort in terms of the concentration of the constituents sampled. The owner plans to submit a second waiver request to the state within the next 2 to 3 months.

REFERENCES AND DATA SOURCES

1. Groundwater evaluation and monitoring report, prepared by hydrogeological consultant (1982).
2. Letter from hydrogeological consultant to state regulatory agency pertaining to groundwater monitoring requirements (1982).
3. Letter from state regulatory agency to facility opeator concerning groundwater monitoring reporting requirements (1981).
4. Information obtained during site visit, 12 May 1983.
5. Telephone conversation of M. Ghassemi to hydrogeological consultant, 27 May 1983.

CASE STUDY NO. 2

1.0 GENERAL DESCRIPTION AND HISTORICAL BACKGROUND

Two on site FML-lined surface impoundments serve this pesticide formulation and packaging facility which is located in an alluvial valley of the Southwest with a dry-summer subtropical climate. The plant is engaged in the wholesale and retail sales and distribution of agricultural chemicals and fertilizers, and houses a number of storage tanks and containers. The formulation of all pesticides, both liquid and dry, involves blending only. Empty containers are accumulated in an empty drum storage area and disposed of as required by hauling to a secure landfill or, whenever possible, treated and reconditioned by a recycler.

Wastewater originates from the wash-down of pesticide formulation-packaging areas and application equipment, and is discharged to a lined evaporation pond ("wash-down pond"). The wash-down pond, which was placed in service in 1979, is lined with two layers of PVC sheet with a leak detection system. Steam cleaning and vehicle wash-down is collected in a recently-constructed pond ("rinse water pond"). The rinse water pond is lined with CPE and PVC, and has a leak detection system.

2.0 BASIS FOR SITE SELECTION

The ponds were located on site to facilitate the collection of pesticide rinse waters generated within the plant. No environmental impact assessment or geotechnical investigation was required or performed in connection with siting.

3.0 DESIGN, CONSTRUCTION, AND INSTALLATION FIRMS UTILIZED

The wash-down pond was designed and constructed by the owner, with input from the state, using contract labor. The PVC sheeting, manufactured by Goodyear, was installed by the contractor. The rinse water pond was designed and constructed by a local contractor.

4.0 DESIGN CRITERIA

4.1 Purpose of the Impoundments

The purpose of both SIs is storage and disposal of pesticide wastewater via evaporation.

4.2 Waste Characteristics

Wastewaters from any of the areas that wash into the lined ponds contain only dilute quantities of pesticides. The amount of wastewater going into the lined ponds varies because of the "batch" nature of the washing operation. The plant operator has reported that the amount of water used probably never exceeds 400 gallons at a time. Pesticides that could be present in rinse waters at any given time include: alkylanyl polyoxyethylene glycols, Bortran, Captan, BT Berlina, Dimethoate, Malathion, Carbaryl, Naled, Diazinon, Kelthane, 4,6-Dinitro-O-Sec-Butylphenol, and sulphur.

4.3 Service Life

No data on the service life of the ponds were required by the state regulatory agency or reported by the owner.

4.4 Site Hydrogeology

No hydrogeological studies were performed prior to pond construction to develop basis for design. Ground water in the area is at 215 feet and generally of good quality (conductivity ranging from 215 to 750 mhos). Beneficial uses of ground water include domestic supply, agricultural supply, and industrial supply.

4.5 Waste-Liner Compatibility

No waste-liner compatibility testing was required or performed. The operator relied upon chemical-liner compatibility tables supplied by the PVC manufacturer.

4.6 Soil Permeability

No soil permeability tests were performed prior or subsequent to pond design. No data on soil characteristics at the facility could be located.

4.7 Regulatory and Permit Requirements

Wastewater discharge requirements were promulgated after the wash-down pond had been constructed, but before the installation of the rinse water pond. Prior to the establishment of permit requirements for this facility, state officials suggested that the owner install an FML-lined wash-down pond. The owner was at first reluctant but later proceeded with installing liners. To protect the state's waters from potential contamination, the state notified the owner of the following requirements (1):

- The Discharger shall maintain at least one foot of freeboard in the lined pond.
- The lined pond shall be protected from inundation by flood having a frequency of occurrence of one in 100 years.
- The discharge of pesticide contaminated water or wastewater to facilities not rendered impervious to percolation (no faster than 10^{-8} cm/sec) is prohibited.
- The discharge of pesticide contaminated water or wastewater to surface water, surface water drainageways or canals is prohibited.
- The Discharger shall supply the Executive Officer with complete as-built plans and specifications and other information necessary to demonstrate the ability of the facility to comply with the requirements.
- Monitoring stations shall be established so that representative observations of the pond influent and fluid level (freeboard) may be obtained on a monthly basis.
- Monthly observations of the leak monitor station must be conducted so that any wastes which might percolate through the synthetic membrane may be noted and sampled. Should leakage be detected, the Discharger shall immediately determine corrective measures necessary to ensure compliance with this order.

4.8 Cost Considerations

No data were available on consideration of costs as criteria in design.

5.0 DESCRIPTION OF DESIGN AND DESIGN SPECIFICATIONS

5.1 Dimensions and Configurations

Wash-down pond: 48' x 28' x 5'.

Rinse water pond: 30' x 20' x 3'.

Ponds are designed for operation with one foot of freeboard.

5.2 Liner

The wash-down pond is lined at the bottom and slopes with two layers of Goodyear Vinaliner PVC sheeting which sets as the primary liner. The bottom of the pond is underlain by one foot of gravel and a secondary 30-mil PVC liner (this liner does not cover the side slopes). The primary liner is anchored in trenches along the edge of the pond.

The rinse water pond is lined with 20-mil CPE and underlain by one foot of sand and a 10-mil PVC chemical and solvent resistant secondary liner. Both liners extend along the bottom and side slopes of the rinse water pond. Side slopes on this pond are 1.5:1.

5.3 Foundation Preparation, Leak Detection System, and Backfilling

No data were available on foundation preparation for either pond.

The wash-down pond leak detection system consists of a single 3-inch perforated PVC pipe extending half-way across the pond bottom and connecting to an observation well. In the rinse water pond, a one-inch perforated PVC pipe and monitor station make up the leak detection system.

The rinse water pond liner system is covered with 1-1/2 feet of soil. There is no backfill cover on the wash-down pond.

5.4 Inlet/Outlet and Other Structures and Provisions

A 3-inch and a 5-inch pipe deliver wastewater to the wash-down pond from the dust mill and pesticide formulation areas, respectively. Cement was placed around the appurtenance of each pipe to prevent leakage. Wastewater is delivered to the rinse water pond via an 8-inch overflow pipe. Both ponds are fenced, locked to unauthorized personnel, and posted with warning signs.

5.5 Observation Wells and Monitoring System

The leak detection systems from both ponds are equipped with observation wells in order to monitor the presence of seepage. No ground water monitoring is required or performed at the facility.

5.6 QA/QC Specifications

No data is available on QA/QC measures performed in connection with securing and installing liners.

6.0 DEVIATIONS FROM DESIGN, PROBLEMS ENCOUNTERED DURING CONSTRUCTION, AND COSTS

6.1 Deviations From Design

The owner recently installed a 1/4-inch layer of fiberglass over each pond to give added protection against deterioration of the liners and a better surface for cleaning.

A newly-installed 20,000 gallon wastewater storage tank is used to control the liquid level in the wash-down pond. The tank gives added protection against overflow in the event of leakage from other bulk storage that pond to give added protection against deterioration of the liners and a better surface for cleaning.

6.2 Problems Encountered During Construction

No data are available.

6.3 Cost Data

No data are available.

7.0 PERFORMANCE DATA AND OPERATING EXPERIENCE

7.1 Liner Performance

To date, no performance deviations have been noted by the operator or the state regarding the liner systems in both ponds. The owner began reporting flow rates, liquid depth, freeboard height, and leakage observations of the wash-down pond to the state in June 1981. As of October 1983, there has been no liquid in the percolation monitoring observation tube. This is strong evidence that the wash pond liner system is performing well.

Since the rinse water pond is relatively new and an adequate data base, including information on leakage noted (if any) in the observation well, is not yet available, an assessment of the liner performance for this pond cannot be made at this time.

REFERENCES AND DATA SOURCES

1. State Waste Discharge Requirements, 1981.

2. Self-monitoring reports, 1981-1983.

3. Various correspondence between State and owner.

CASE STUDY NO. 3

1.0 GENERAL DESCRIPTION AND HISTORICAL BACKGROUND

This commercial facility is located in an area with a Mediterranean climate. Surrounding lands are marshy, and nearby land uses include solid waste disposal and flood control.

The facility actually consists of two adjacent sites. Site A consists of a liquid waste treatment plant and waste settling and storage ponds; Site B consists of a series of evaporation ponds. All ponds at both sites are of earthen construction with clay liners. Wastes from various local industries are received initially at Site A; after treatment, they proceed to the Site B ponds via an eight-inch diameter above-ground pipeline for ultimate disposal by evaporation.

Site A has been used for waste treatment, storage, and disposal for approximately thirty-two years. Until 1971 its ponds were used primarily for evaporation. A treatment plant was built on site in 1969-71 and began operation in 1971. At this time, Site A's ponds were converted to use for settling, batch segregation and storage, and sludge disposal, and Site B was developed into evaporation surface impoundments. Originally, the two sites were connected by a six-inch underground pipeline; the above-ground pipeline was added in 1978, and the underground pipeline was left in place as a backup system. Surface impoundments on both sites have been upgraded several times since 1971; currently, 15 of Site A's 21 acres are devoted to 8 surface impoundments (SIs), and 74 of Site B's 130 acres have been developed into 7 SIs. Site A also holds the treatment plant, holding tanks, an oil processing area, and offices and laboratories.

The data and information presented and discussed here are primarily those available in the state files. The owner, however, was given the opportunity to review and comment on the draft of this Case Study report and this final report incorporates the owner's comments. According to the owner, the information in the state files is only a fraction (perhaps about 10%) of the data which have been or are continuously being generated by the owner in connection with various hydrogeological and engineering studies. The owner sees no reason to report all information to state or even to document the chronology of various events and studies.

2.0 BASIS FOR SITE SELECTION

Although there is no documentation of the site selection considerations, the availability of reasonably priced land close to the industry could have been the primary basis for original selection of Site A for waste treatment, storage, and disposal. Although records are not clear on the exact date when operating permits were first issued for Site A (perhaps sometime in late 1950's), monitoring wells are known to have been in place and operating in 1964. In 1971 the state required that additional studies be done to ensure the facility met the requirements of the permit. At the same time, the owner proposed to expand operations by developing Site B. Studies of both sites were performed by a consulting firm in 1971, and included geotechnical and hydrogeological investigations and environmental impact analysis. Geotechnical testing included soil boring tests, in-place vane shear strength tests, soil classification, soil moisture content and dry density determinations, and triaxial laboratory permeability tests. Surface examinations and a review of the geologic and engineering data available regarding the site were conducted to determine the susceptibility of the site to flooding or earthquake damage. Rainfall and evaporation rates were considered to determine the suitability of the site for its intended use, waste evaporation. The proximity of other land uses and the potential for urban development in the area were considered with respect to the possibility of the threat of pollution or environmental degradation, odor problems, visual impacts, and site access and safety.

3.0 DESIGN, CONSTRUCTION, AND INSTALLATION FIRMS UTILIZED

The identity of the designers and constructors of the original facilities was not available in the data obtained. In more recent years, various outside consulting firms have been retained to conduct hydrogeologic and geotechnical investigations of the site, to drill monitoring wells, etc. Outside consultants and contractors have also been used to recommend levee design changes and to perform the recommended construction work. Several of the original ponds at Site B were constructed by a government agency which used the ponds to hold silt and sand dredged from the adjacent flood control channels.

4.0 DESIGN CRITERIA

The criteria used for the original design of the Site A surface impoundments were not available. However, as the facility was improved over the years, design criteria were described in technical reports by consultants and in correspondence between the owner and regulatory agencies. For the Site B surface impoundments, both the original design basis and the basis for later improvements were available. In general, the following descriptions of design criteria are based on the most recent criteria available; where a history of the criteria seems necessary, it is supplied.

4.1 Purpose of Surface Impoundments

The purpose of the Site A impoundments are settling of solids, batch segregation and storage, and sludge disposal. Site B impoundments are for the purpose of storage and ultimate disposal of liquid wastes via evaporation.

4.2 Waste Characteristics

The facility accepts a wide variety of liquid wastes from petroleum refineries and from the steel, chemical and semiconductor industries. In 1982, a total of 53 million gallons of wastes were received, of which 34 percent were oily water and brine wastes, 24 percent were alkaline solutions, and 16 percent were acid solutions. The remaining wastes included solutions of solvents and heavy metals, paint sludges, tank bottom sediments, cyanide, pesticides, drilling mud, and other chemical wastes (1).

4.3 Regulatory and Permit Requirements

Waste water discharge requirements were first established by the state in a permit which was issued to the facility in late 1950's. A self-monitoring program was set up in 1965. The permit was revised in 1971. The owner retained a consulting firm to determine whether Site A's existing facilities were meeting the requirements of the revised permit. Specific requirements addressed by the consultant included the following (2):

- The treatment or disposal of waste shall not create a nuisance.
- Waste material and any water that has contacted waste material shall not be placed in any position where it can be carried from the disposal site and discharged into waters of the State.

- The disposal site shall be adequately protected against erosion, runoff and flooding by tidal and storm waters. Adequate protection is defined as protection from at least a 100-year flood.
- Waste material or any of its components shall not seep through the perimeter levees or the bottom of the disposal ponds.
- Waste material or any of its components shall not exist on the ground surface anywhere outside of the waste ponds, or in the shallow groundwater at any point.

To make this determination, the consultant investigated site hydrogeology, engineering properties, and performance. These are discussed in later sections of this report.

In 1978, the permit was again updated, and the following changes in requirements were made (3):

- The disposal area shall be protected at all times from any washout or erosion of wastes or from any threat of inundation.
- Vertical or lateral movement of wastes or leachate from the disposal areas ... shall be prevented by an impermeable dike or barrier ... This dike shall be keyed into impermeable natural substrata and shall provide a minimum of five feet of material with a permeability not to exceed 1×10^{-8} cm/sec or equivalent.
- Useable groundwaters shall not be degraded as a result of disposal operation.

In addition, there are requirements for a self-monitoring program which includes visual inspections and groundwater, waste input, receiving water, leachate discharge, and surface water monitoring.

4.4 Site Hydrogeology

Hydrogeological factors were considered as early as 1971 (2,4). The following data describe the two sites:

Evaporation Rate: 55 inches/year water, 48 inches/year waste.

Precipitation: 18 inches/year.

Groundwater Conditions: Very poor quality groundwater exists 3 to 5 feet below ground surface. Total dissolved solids content of groundwater was reported as 20,000 to 80,000 mg/L at Site A and 15,000 to 71,000 mg/L at Site B in the 1971 studies. There is no known useable groundwater immediately under the site. The direction of groundwater flow at Site A is essentially from the southwest to the northeast. At Site B, the hydraulic gradient is in the form of an oval mound over the site.

Flooding Potential: The site is protected from at least the 100-year flood level by 2 nearby flood control canals. It is near a large bay and is separated from it by relatively flat, marshy land.

Fault Zone: The inferred trace of an active fault traverses the northeast corner of Site B. Although there were indications that a fault might exist in the area in 1971, it was not known to be active and its exact location could not be determined due to the plastic nature of the local soils. More conclusive information was not obtained until 1982, when testing revealed seismic evidence of a possible zone of disruption in the near subsurface, and suggested movement within the upper 100 to 800 feet of material (5).

4.5 Soil Permeability

Soil permeability data from 1971 (2,4) indicate subsoil permeabilities ranging from 10^{-5} to 10^{-8} cm/sec for Site A and 10^{-6} to 10^{-8} cm/sec for Site B. Site A is underlain by 150 to 700 feet of organic clays, followed by marine sandstone and shale bedrock formations. The top one to four feet of soil at Site B consists of silty, clayey sands dredged from the two flood control channels which abut the property. The next 700 to 800 feet of soil is sandy and silty clay, which is underlain by marine sandstones and shales.

The 1971 study concluded that the on-site clays were suitable for the containment of liquid wastes because (2):

> Permeability tests performed on compacted samples of the near surface clays indicate seepage through any section of reasonably compacted clay to 90 percent of the maximum dry density ... will be negligible. The laboratory determined coefficient of permeability for undisturbed native soil and a disturbed sample compacted between a range of 80 percent and 90 percent of the maximum dry density indicates a magnitude of 10^{-6} cm per sec.

The 1978 permit required wastes to be contained by "a minimum of five feet of material with a permeability not to exceed 1 x 10^{-8} cm/sec or equivalent" (3). It also required the facility owners to demonstrate compliance or upgrade the facility within one year. The bottoms of the SIs were determined to provide equivalent protection; the results of dike studies are presented in Section 5.2.

4.6 Waste-Liner Compatibility

No waste liner compatibility testing was required or performed. The selection of the earthen liners was most probably based on local availability; in the case of Site A, other liner materials were unavailable when the site was first used for waste disposal.

4.7 Cost Consideration

No data are available on the consideration of costs as design criteria (e.g., liner or contractor selection).

5.0 DESCRIPTION OF DESIGN AND DESIGN SPECIFICATIONS

5.1 Unit Sizes (See Figure 2 for relative locations)

Site A (estimates):

- 1 pond of approximately 7 acres
- 2 of approximately 2 acres
- 2 of approximately 1 acre
- 3 of approximately 0.6 acre

Site B (6):

- Pond A - area 10 acres, depth 6 feet
- Pond B - area 20 acres, depth 6 feet
- Pond C - area 20 acres, depth 6 feet
- Pond D - area 10 acres
- Pond E - area 5 acres, depth 8 feet
- Pond F - area 6 acres, depth 8.3 feet
- Pond G - area 3 acres, depth 8 feet

5.2 Levees

In 1971, existing Site A levees had unconfined shear strengths of 700 to 1600 pounds per square feet (psf), permeabilities of 10^{-6} cm/sec, a maximum height of 11 feet, and an average density of 124 pounds per cubic foot (pcf). Stability analysis of the levees indicated that the factor of safety against a major slope failure appeared to be at least 1.5, and that the factor of safety against base failure was 1.7. One section of the north levee, however, was constructed on an older fill consisting primarily of refuse and miscellaneous trash. The extreme westerly end of this levee had subsided as the underlying refuse foundation failed by spreading laterally into the adjacent pond. This levee was repaired by constructiong a "displacement fill": the levee height was raised so that most of the unstable fill would be displaced. After the refuse fill was displaced, the levee would settle into position (2).

The 1978 state permit required the site owners to determine whether or not the existing levees met the new permit requirements within one year. Borings indicated that the south levee of Pond A at Site A did not meet the permeability requirement of 1×10^{-8} cm/sec. This was because a gravel road surface was not scarified when the south levee was originally repaired.

Per agreement with the state, the owner improved the levee system late in 1979 (8) by constructing a 3- to 5-ft thick impervious compacted clay trench from the north levee of Pond A along the east levee approximately 1510 feet to the southern flood control levee. This clay trench was keyed into native clays at least four feet, and also into the north levee of the pond and into the flood control levee, which is itself keyed into native clays. (Visual inspection during construction indicated that the eastern levee of Pond A was keyed and intact.) Permeabilities in the clay trench were reported to be between 1×10^{-8} and 9×10^{-8} cm/sec. Side slopes were 1.5 to 1 and the top width was approximately 18 feet.

The 1971 plans for Site B levee construction called for levees four feet high with inside and outside slopes no steeper than 1.5:1 and a top width of at least ten feet. The various ponds were constructed at different times. Ponds B and C were built in 1971 in the following manner (9):

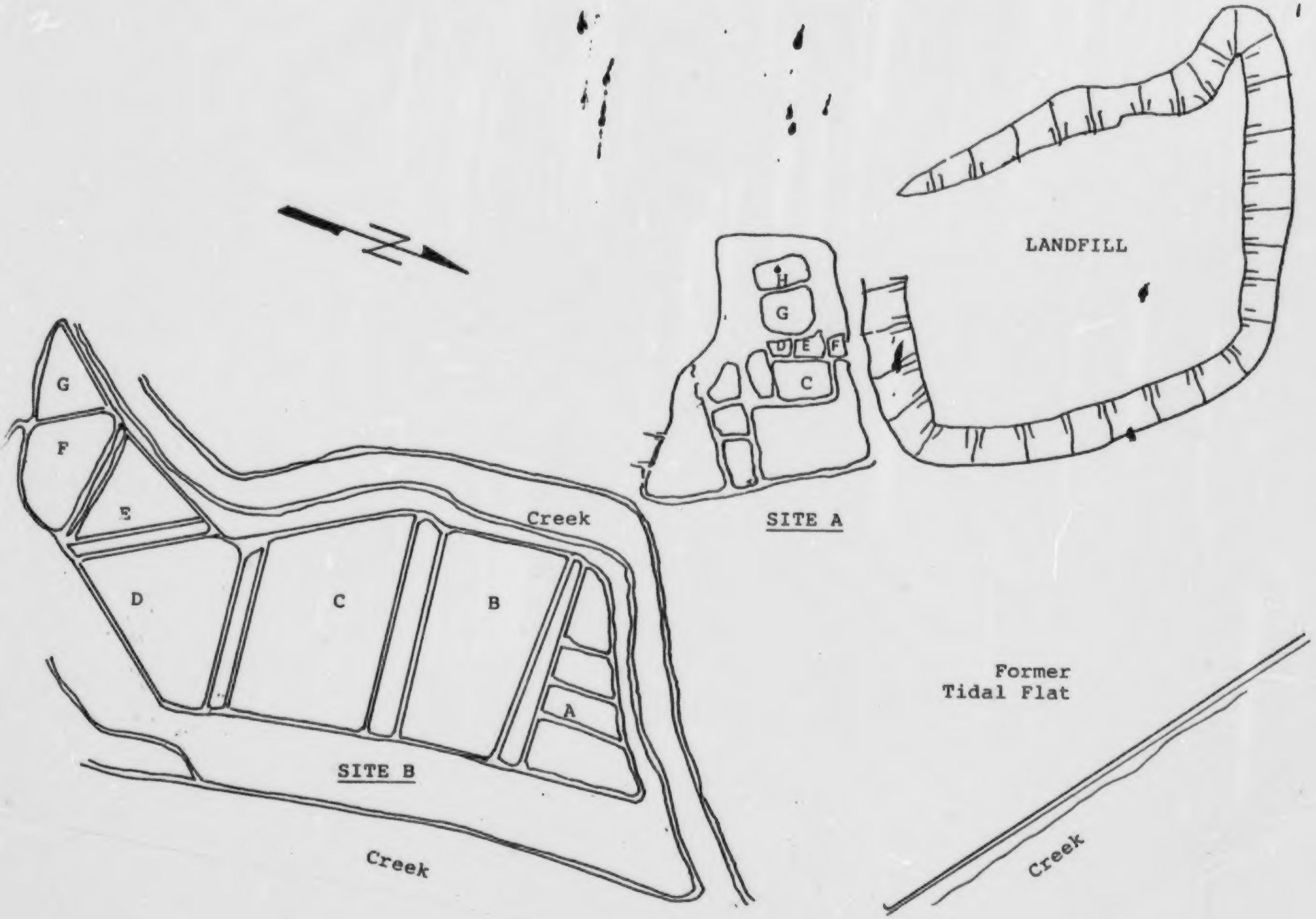
LANDFILL
H
G
D
E
F
C
SITE A
Former
Tidal Flat
Creek
Creek
G
F
E
D
C
B
A
SITE B
Creek

Figure 2. Facility Pond Layout

- The first two lifts of fill were held to a maximum 9-inch thickness after compaction to 80 percent of maximum dry density.
- Three 20-cubic-yard scrapers, three track-mounted dozer tractors, and a 3500-gallon water truck were used during construction.
- Prior to placement of fill, the embankment foundations and borrow areas were stripped of all surface vegetation and of loose, disturbed, and otherwise unsuitable foundation materials. The exposed subgrade below the embankments was then scarified and moisture conditioned to provide an impervious bond at the interface between the embankment fill and the underlying natural soil. Much of this soild was originally hydraulically dredged and pumped into the area during the deepening of the flood control channels along the eastern and western sides of the property. This resulted in a highly variable soil mixture and moisture content, depending on the depth of excavation. Where possible, the hydraulic fill soils and the underlying natural silty clays were mixed and moisture conditioned.
- The levee fill material was obtained from within the pond areas, and consisted of fine sand, silt, and clay.
- Average percent compaction achieved (after recompaction and retesting of areas that failed initially) was 97 percent.

The initial plans for the levees specified side slopes no steeper than 1.5 to 1, initial height of 4 feet, and 10-foot minimum top width, with an eventual levee height of 6 feet to be achieved at a later date.

Pond A was built in 1973. Construction was essentially identical to that of Ponds B and C. The average percent compaction achieved in the levees was 93 percent (10).

The Pond D and G levees were constructed in 1973 as part of channel improvement work by a government agency (11). The levees were constructed to contain soil material dredged from the flood control channels. The government agency's project plans indicate that the levees were to be constructed as required, and no "as built" plans or construction data are available. The levees had an average height of 7.5 feet and were sloped at about 1:1, with a top width of 15 feet except where the northern and western levees had recently been widened to 30 feet to accommodate truck traffic.

Until 1978, Pond D had been used as a sludge biodegradation/soil blending area. To convert Pond D to an evaporation pond, consultants recommended that the permeability of the levees be decreased from current values of 10^{-6} - 10^{-8} to 10^{-8} or less, in compliance with the 1978 state regulations. Alternative designs for cut-off walls were submitted by the consultant that would decrease the permeability to acceptable levels and preserve the structural integrity of the dikes (static and dynamic safety factors of 1.86 and 1.23, respectively).

Work performed on Pond D sometime between 1978 and 1980 consisted of subdividing the pond with a clay levee keyed into the natural clay foundation and by constructing a 3-foot thick clay core, also keyed into natural clay, along the center line of the levee north of the new subdividing dike (12). The rest of the original Pond D and all of Pond G levees were upgraded in 1980. The upgrading consisted of construction of a 3-foot compacted clay key tapered up along the inside levee face. Another internal levee (south of the first one) in the original Pond D was also constructed at this time, so that Pond D is now three ponds, D, E, and F. Permeabilities in the new dikes and the cutoff walls were in the 10^{-8} cm/sec range (13).

5.3 Leachate Collection System

A subdrain trench was in place as early as 1971 along the eastern boundary of Site A. This subdrain trench was designed to drain into a collection sump from which the escaping fluids would be automatically pumped back into the evaporation ponds. The sizes of and depths of the trench and pump were not available. In 1971, consultants proposed installing a new subdrain along the north side of the property; this subdrain would drain to a sump near the northeast corner of the site where collected fluid would be pumped back into the evaporation ponds. The recommended design called for a 5-foot deep trench, the top 18 inches of which would be compacted clay, followed by 42 inches of permeable material (2). There is no indication in the data of whether or not this subdrain was constructed. Correspondence in March 1979 refers to a "french drain system" installed "some years ago", but it is unclear exactly what or where the system is (14). The french drain collection system was abandoned after the completion of the improvements to the eastern Pond A levee in 1979 (5).

There is no evidence in the data of any leachate collection system for Site B.

5.4 Inlet/Outlet and Other Structures

The outlet for Site A is also the inlet to Site B and consists of a 220-foot long, 8-inch diameter coated steel pipe encased within a 12-inch steel pipe. It crosses one of the flood control channels and is placed on supports on each side of the creek. The pipeline's purpose is to transport treated industrial wastes to Site B's evaporation ponds (16). There is no outlet for Site B ponds, since they serve to evaporate wastes. Inlet structures for Site A are not described, nor is there any mention of pipelines or other structures connecting the various ponds.

Other structures on site include fences around the property and the treatment plant, holding tanks, offices, and laboratories at Site A.

5.5 Groundwater Monitoring System

Seventeen groundwater wells are currently being monitored; three wells are at Site A and fourteen are at Site B. These wells were constructed at various times, and design data for all of them were not available. Moreover, it appears that wells were renumbered at least once (3,17). As a result, it is unclear exactly which wells are referred to by the boring logs, and it is possible that all monitoring data recorded for a given well number may not be the results of sampling from only one well.

Boring logs were available for wells 8, 12, 13 and 14, which were placed in 1982. Groundwater was first encountered in all borings during drilling at depths ranging from 7 to 10 feet below the existing ground surface. All four wells were constructed with 4-inch diameter solid ABS pipes and a 5-foot PVC section perforated with 6 rows of 0.02-inch slots. Total well depths ranged from 16 to 19 feet, and the tops of the perforated sections ranged from 5 to 9 feet. The space between the pipe and the boring wall was backfilled with peagravel to about one foot above the top of the perforated section, and a one-foot bentonite plug was placed over the gravel pack to provide a seal against surface water infiltration. The remaining space was backfilled with concrete (17).

The data indicate that wells numbered 4, 5, 6, and 8 were drilled before September 1971 and that wells 1, 2, 3, and 7 were drilled in October 1971. Wells 1, 2, and 3 were drilled to a depth of 25 feet, and 5-inch diameter PVC pipe with the bottom 10 feet slotted was installed (9). Well 8 was sealed in 1982 and new well 8 was placed at that time.

5.6 Quality Assurance and Quality Control Specifications

Quality control measures reported in the data related primarily to levee construction work. Soil lift thicknesses and the percent of maximum compaction to be attained were specified; field density test locations were selected on the basis of random sampling, and additional tests were performed in areas which appeared to have low relative compaction. Areas which were initially determined to be unsatisfactory were reworked until the required density was obtained. Required densities varied from 80 to 90 percent of Proctor density, depending on the levee and soil type (9,10,11).

6.0 DEVIATIONS FROM DESIGN AND PROBLEMS ENCOUNTERED DURING CONSTRUCTION

6.1 Deviations from Design

Original design specifications had to be modified at least twice during site development. During the 1971 construction of Ponds B and C at Site B, it was discovered that the natural soils near the ground surface beneath the embankments were softer and had a higher moisture content than anticipated. As a result, the first two lifts of fill were held to a maximum 9 inches after compaction to 80 percent of maximum dry density (9). (Original specifications were not available.)

A more significant design change occurred in the course of the 1979 upgrading of Site A levees. Initially, a consultant had planned to upgrade the levees by placing a slurry trench cutoff wall. The consultant worked with another consultant to develop an appropriate slurry mixture of bentonite, cement, and marasperse-gel. After three weeks of long-range permeability laboratory testing of potential slurry mixtures, it became evident that a suitable mix would not be found. Therefore, an entirely new design approach, using a compacted clay core cutoff wall, was developed (8).

6.2 Problems Encountered During Construction

There were problems with monitoring well construction at Site B in 1971. Due to the soft nature of the soils, the holes tended to squeeze shut before gravel could be packed between the PVC pipe and the boring wall. However, when the wells were checked following installation, three were found to be open to their full casing depth. The fourth well (No. 7) was found to be filled with soft, silty clay which had apparently forced its way into the casing at the time of installation. It was recommended by the contractor that all wells be cleaned out with air or water before use (9).

6.3 Level of Contractor and QA/QC Competency

Problems with contractors occurred during the 1979 Site A levee upgrading. An earthwork contractor, chosen in part because of his experience with similar work, was found not to consistently meet moisture content and density requirements due to the use of unsuitable equipment and the lack of aggressive supervision. This contractor was removed from the job by the site owners and a new contractor was obtained. Tests were performed by a consultant to identify sections installed improperly by the first contractor, and sections which did not meet specifications were either excavated and replaced or reworked and retested. The second contractor had the proper equipment and supervision to do the work, and was able to obtain good density values (8).

7.0 PERFORMANCE DATA AND OPERATING EXPERIENCE

7.1 Groundwater Monitoring Data

Although groundwater monitoring wells have been in place at least since 1971, groundwater monitoring data were available only for 1979, 1980, and 1982. Analysis of this limited data does not lead to any significant conclusions. There are no significant differences between data for the three different years. The apparent renumbering of wells (2,16) makes examining changes in water quality through time difficult. Data regarding the exact direction of groundwater flow are sketchy, so it is difficult to make meaningful comparisons of concentrations from the various wells. The gradient is reported to be in the shape of an oval mound over Site B, but the exact location of this oval mound is not specified (18). It is possible that only one well is "upgradient" at Site B, and as this well is on the dike between Ponds C and D, it is not likely to be an indicator for upgradient groundwater quality. Groundwater flow is said to be from southeast to northwest at Site A (17), which means that there are no downgradient wells for Site A at all. The upgradient Site A wells are also downgradient of Site B, so they may not be good indicators of Site A performance.

1982 groundwater data are presented in Table 19 (1) and statistical analyses of that year's data are presented in Table 20. Observations of the sampled water indicate that the water is rarely clear and often has a sulfide odor. Phenols and total inorganic chlorinated hydrocarbons were never reported above detection limits. The detection limits of the trace elements

TABLE 19. 1982 GROUNDWATER MONITORING DATA

Date	Time	Well Depth	Depth Sample	Color	Odor	As	Cd	Cl	Total Cr	Pb	Cu	Ni	pH	TOC	TDS	Phenolic Compounds (ppb)	TICH (ppb)
5/17/82	12:00	17'	6'	yellow	sulfide	.03	<.005	12700	.1	.13	.05	.09	7.0	36	24300	<30	<0.5
10/ 4/82	out of service																
5/17/82	11:45	20'	6'	yellow	none	.04	<.005	8900	.04	.07	.03	.04	6.8	163	20300	<30	<0.5
10/ 4/82	—	20'	3'	yellow	sulfide	<.02	<.04	12100	<.1	<.2	.04	<.2	7.0	557	27300	<30	<0.5
5/17/82	11:30	15'	6'	dirty yellow	sulfide	.07	.006	13000	.53	.01	.15	.32	6.9	50	22700	<30	<0.5
10/ 4/82	—	15'	3'	yellow	none	<.02	<.04	8300	<.1	<.2	.04	<.2	7.5	98	21400	<30	<0.5
5/17/82	11:00	11'	6'	yellow	none	.02	<.005	3800	.04	.12	.03	<.03	7.0	11	7800	<30	<0.5
10/ 4/82	—	11'	5'	clear	none	<.02	<.04	4000	<.1	<.2	<.04	<.2	6.7	58	8700	<30	<0.5
5/17/82	under water																
10/ 4/82	—	-	4'6"	lt. yellow	none	<.02	<.04	5210	<.1	<.2	<.04	<.2	7.0	151	11900	<30	<0.5
5/17/82	10:45	11'	6'	yellow	none	.03	.007	12300	.07	.12	.06	.04	7.2	10	25600	<30	<0.5
10/ 4/82	—	11'	6'	lt. yellow	sulfide	<.02	<.04	11700	<.1	<.2	<.04	<.2	7.2	146	23900	<30	<0.5
10/ 4/82	—	-	4'5"	yellow	none	<.02	<.04	2290	.1	<.2	<.04	<.2	7.0	102	4900	<30	<0.5
5/17/82	10:30	13'	6'	yellow	none	.05	<.005	6400	.03	.06	.03	<.03	6.7	<1		<30	<0.5
10/ 4/82	—	13'	3'	clear	none	<.02	<.04	5000	<.1	<.2	<.04	<.2	6.9	81	11050	<30	<0.5
5/17/82	3:25	17'	6'	yellow	sulfide	.01	<.005	10000	.05	.10	.05	<.03		5	17900	<30	<0.5
10/ 4/82	—	17'	6'	lt. yellow	sulfide	<.02	<.04	8340	<.1	<.2	.04	<.2	6.9	288	19500	<30	<0.5
5/17/82	3:15	10'	6'	gray	sulfide	.01	<.005	10200	.06	.12	.05	<.03	6.8	16	18400	<30	<0.5
10/ 4/82	—	10'	6'	clear	sulfide	<.02	<.04	8760	<.1	<.2	<.04	<.2	7.5	214	19600	<30	<0.5

(Continued)

TABLE 19. 1982 GROUNDWATER MONITORING DATA (Continued)

Date	Time	Well Depth	Depth Sample	Color	Odor	As	Cd	Cl	Total Cr	Pb	Cu	Ni	pH	TOC	TDS	Phenolic Compounds (ppb)	TICH (ppb)
5/17/82	out of service																
10/ 4/82	—	-	5'	lt. yellow	sulfide	<.02	<.04	24400	.1		<.04	<.2	6.4	204	61070		0.5
5/17/82	out of service																
10/ 4/82	—	-	10'	yellow	none	<.02	<.04	17700	<.1	<.2	.08	<.2	6.6	611	43600	bottle broken	
5/17/82	out of service																
10/ 4/82	—	-	6'	clear	none	<.02	<.04	7300	<.1	<.2	.08	<.2	6.8	20	16400		
5/17/82	10:30	20'	6'	yellow	none	.04	<.005	9500	.06	.12	.05	.04	7.2	12	17900	<30	<0.5
10/ 4/82	out of service																
5/17/82	out of service																
10/ 4/82	—	20'	5'	lt. yellow	none	<.02	<.04	8340	<.1	<.2	<.04	<.2	8.2	123	18800	<30	<0.5
5/17/82	11:00	22'	6'	gray	none	.04	<.005	6600	.11	.11	.08	.07	7.0	<1	13200	<30	<0.5
10/ 4/82	—	22'	4'5"	clear	none	<.02	<.04	5840	<.1	<.2	<.04	<.2	7.5	45	11900	<30	<0.5
5/17/82	10:45	12'	6'	gray yellow	none	.01	<.005	10400	.09	.31	.04	.05	7.2	<1	21400	<30	<0.5
10/ 4/82	—	12'	6'6"	lt. yellow	none	<.02	<.04	10800	<.1	<.2	.04	<.2	8.7	88	21100	<30	<0.5
5/17/82	out of service																
10/ 4/82	out of service																

analyzed apparently increased between the first and second analysis; this may have affected the statistical analyses of the data. Trace element concentrations are low, while chloride, total dissolved solids (TDS), and total organic carbon (TOC) are high. pH is neutral on the average.

Background water quality data for TDS indicate concentrations of 15,000 to 80,000 mg/l (2,4). This saline groundwater assertedly trapped in a non-echargeable aquifer (29), is unsuitable for drinking water. The TDS and chloride values reported for the site in 1982 (see Table 20), although high in an absolute sense, are not unreasonable considering background water quality.

7.2 Air Pollution and Odor Problems

Most of the reported odor problems seem to have been caused by sludge disposal operations at Site B. The first available documentation of odor problems is in 1976, when the facility owners alluded to previous odor complaints from the agency and reported that they have not received any complaints since they have proceeded with closing a sludge pond at Site B.

In 1978, odor problems occurred again at Site B. Pond D had been used for farming of industrial waste sludges. The combination of a particular sludge and excess storm water in the land-farming areas resulted in sulfide odors. Neighboring homeowners filed a complaint with a government agency, and subsequent testing resulted in ten air emission citations. In the previous year, the facility had been cited 47 times for air pollution violations.

To abate the odor problem, the facility owners treated the sludge with lime and chlorine, and converted Pond D into two solar evaporation ponds. This conversion process took some time, as it included subdividing Pond D into Ponds D and E by the addition of a new dike, and upgrading existing dikes for the containment of liquids (20). The sludge was removed to another commercial facility.

Odor problems became an issue again in 1980, when the owners requested permission to accept pesticide wastes which had been causing odor problems at a nearby facility. The owners developed a plan to control the odors which consisted of adding chemicals to the waste and mixing them into the wastes during discharge from the truck to the receiving pond. Permission to accept the waste was granted in September 1980, and the waste was placed in Ponds F and G of Site B (21).

In June 1981, the facility owner requested permission from the state to pump the remaining liquid pesticide wastes into a shallower pond (C) so that they would evaporate within 6 weeks instead of the estimated 1 to 2 years necessary if the wastes remained in Ponds F and G. This request was granted, subject to conditions designed to limit pesticide contamination, and no further odor complaints were noted in the data (22). According to the owner (29) there has been only one odor complaint each in 1981, 1982 and 1983 from the same individual.

TABLE 20. STATISTICAL ANALYSIS OF GROUNDWATER MONITORING DATA FOR 1982

Parameter	Concentration Range, mg/L	Concentration Average, mg/L	Standard Deviation, mg/L
Arsenic	0.01 - 0.07	0.019	0.016
Cadmium	<0.005 - <0.04	0.013	0.009
Chloride	2,290 - 24,400	10,172	5,079
Total Chromium	0.03 - 0.53	0.078	0.095
Lead	0.01 - 0.31	0.107	0.048
Copper	0.03 - 0.15	0.057	0.076
Nickel	<0.03 - 0.32	0.085	0.059
Total Organic Carbon	<1 - 611	118.9	157.1
Total Dissolved Solids	4,900 - 61,070	20,425	11,472
Phenols	<0.030	<<0.030	0
Total Inorganic Chlorinated Hydrocarbons	<0.0005	<0.0005	0
pH (Units)	6.4 - 8.7	7.1	0.5

7.3 Seepage, Spills, and Other Performance Data

Seepage problems were noted at Site A as early as 1971. According to consultants, "the most extensive seepage ... was occurring through exterior side slopes adjacent to the northwest pond where levees had been constructed on an older refuse fill" (2). The actual flow was through the refuse fill (underneath the low permeability clay levee). This seepage problem was corrected when the displacement fill was placed on these levees.

During the same investigation, it was discovered that the existing subdrain trench was not operating at the required efficiency and that fluids collected in the trench were rising to the ground surface instead of being pumped back to the ponds. Fluids observed in the backhoe pits excavated east of the subdrain trench contained a heavy oil slick and emitted a strong odor.

In mid-1978, seepage was again noted on the north side of Pond A levee at Site A. Analysis of a sample of the leachate yielded the results shown in Table 21 (23). The composition of this leahate is suggestive of that from a solid waste landfill rather than Pond A, especially in light of the fact that the surrounding hydraulic gradient is south and east (i.e., away from a nearby landfill and towards Pond A). Evaluation of the levees in early 1979 resulted in upgrading of the levees late in 1979 that was intended to bring the site into compliance with the 1978 permit and prevent further seepage. Leachate was noted again in a ditch outside the north levee late in 1980 (24), but data were not available to determine whether the liquid was from the ponds or from a nearby landfill.

Two spills were reported in April 1979, one of which was directly related to pond operations. Rainwater was being pumped from Pond E to Pond G. The Pond G dikes were uneven in height, and one side was covered with tules. As a result, the operator could not determine when the pond had been filled to capacity, and approximately 100 gallons of material were discharged. Sampling data from the spill are reported in Table 22. Corrective measures taken included removing tules, building up the levee at low spots, and pumping water back from Pond G to Pond E. The other spill was an oil spill due to mechanical failure of a trailer support. It involved 65 gallons of heavy oil and affected 2000 square feet. All contaminated grass and soil were removed, and the trailer contents were pumped out. This spill was not due to any failure of the surface impoundments (25).

In the fall of 1978, Pond A of Site A was threatened by a landslide at the adjacent commercial landfill. A sewer outfall pipe was broken by this landslide, and cracks were formed in the edge of the Pond A levee. No data on remedial action were available (26).

In February 1982, the pipeline between Sites A and B was discovered to have ruptured. Approximately 2500 gallons were spilled from the pipeline inspection box on the eastern flood control levee and from an eruption area at the toe of the same levee. Approximately 20 gallons of the material spilled into the flood control channel. Remedial action included booming the

TABLE 21. 1978 LEACHATE COMPOSITION

Parameter	Concentration, mg/L
Chromium	28
Copper	7.0
Lead	121
Iron	25,500
Chemical Oxygen Demand	13,960
pH	2.1 Units

TABLE 22. SPILL ANALYSIS

Parameter	Pond E	Concentration, mg/L 27' Downstream	At Flood Gate
pH	8.2 Units	7.25 Units	7.4 Units
Phenol	0	0	0
Hydrocarbons	0	0	0
Cadmium	0.01	0.01	0.01
Cyanide	0.2		0.2
Chromium	0.3		0.3
Nickel	0.3		0.3

creek and removing 60 gallons of liquid and 90 cubic yards of soil. Pipeline repair work was not described (27).

Monthly inspection reports from 1980, 1982, and the first three months of 1983 were available. They indicated that the 2-foot freeboard requirement was not met in all ponds in all months, but was met approximately 84 percent of the time. No leachate, levee cracking, rodent burrowing, or odors were observed, although some surface water was observed at various observation stations in early 1980. A wildlife surveillance program indicated that no birds were using disposal pond surfaces, but that surrounding and adjacent areas continue to be used routinely by birds and wildlife. Thirty-eight dead birds were found during the 27 months on record (28).

REFERENCES AND DATA SOURCES

1. Self-monitoring Report, January 19, 1983.
2. Consultant's report, October 1971.
3. State Waste Discharge Requirements, 1978.
4. Consultant's report, June 1971.
5. Seismic Study, October 1982.
6. Correspondence, Facility Owners to State Agency, March 24, 1980.
7. Consultant's report, March 1979; correspondence, State Agency to Facility Owners, June 12, 1979.
8. Correspondence, Facility Owners to State Agency, December 28, 1979.

REFERENCES AND DATA SOURCES (Continued)

9. Consultant's report, November 1971.
10. Consultant's report, August 20, 1973.
11. Consultant's report, June 1978.
12. Correspondence, Facility Owners to State Agency, April 24, 1980.
13. Correspondence, Facility Owners to State Agency, August 27, 1980.
14. Correspondence, Facility Owners to State Agency, March 30, 1979.
15. Correspondence, Facility Owners to State Agency, December 1980.
16. Correspondence, State Agency to Facility Owners, June 1978.
17. Consultant's report, August 1982.
18. Consultant's report, December 1982.
19. Correspondence, Facility Owners to State Agency, March 8, 1976.
20. Internal memo, State Agency, June 7, 1978; Correspondence, Facility Owners to State Agency, July 21, 1978.
21. Correspondence, Facility Owners and State Agency, August - September, 1980.
22. Correspondence, Facility Owners and State Agency, June - July, 1980.
23. Internal memo, Facility Owners, July 27, 1978.
24. Correspondence, Facility Owners to State Agency, December 8, 1980.
25. Correspondence, Facility Owners to State Agency, April 10 and 25, 1979.
26. Internal memo, State Agency, July 27, 1981.
27. Correspondence, Facility Owners to State Agency, February 1982.
28. Self-monitoring Reports, Facility Owners, January 1981 and 1983, and April 1983.
29. Data Provided by Facility Owner, June 7, 1983.

CASE STUDY NO. 4

1.0 GENERAL DESCRIPTION AND HISTORICAL BACKGROUND

This fertilizer manufacturing complex is situated on a 140-acre site in an alluvial valley of the Southwest. The complex is located in an agricultural region with a dry-summer subtropical climate and relatively flat topography. The plant began full-scale operation in 1958 with an anhydrous ammonia unit and an ammonium sulfate unit. Major expansions and additions to the plant were made in 1963, 1965, and 1976. The complex currently consists of two anhydrous ammonia units, three ammonium sulfate units, two granular ammonium phosphate units, two phosphoric acid units, one sulfuric acid unit, one liquid ammonium phosphate unit, one nitric acid unit, one ammonium nitrate unit, and one urea unit.

The plant's wastewater storage and disposal facilities have also undergone expansions and improvements. The following is a brief description of the existing surface impoundments used to manage plant wastewaters (see Figure 3):

- A small 1.0-acre unlined sedimentation pond receives blowdown from hot-lime treaters; the solids settle out and the liquid is recycled to the lime treating unit.
- Fourteen acres of unlined gypsum ponds receive intermittent discharges of production water from the ammonium phosphate/phosphoric acid unit. Water from these 11 ponds is recycled through the plant's cooling system and is consumed in the process.*
- An 8-acre FML-lined evaporation pond receives blowdown water from plant boilers and wastewater from water treaters, cooling towers, nitric and sulfuric acid units. Surface runoff is also directed to this pond.*
- A 38-acre FML-lined cooling pond receives wastewater associated with the production of a variety of fertilizers. Water from this pond is recirculated through the plant's cooling system.*

2.0 BASIS FOR SITE SELECTION

Because the sedimentation and gypsum ponds were built before environmental factors became an important issue in siting wastewater facilities, these ponds were constructed on site primarily based on the consideration of land availability. The evaporation and cooling ponds were located on site

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*Wastes generated as a direct result of mining and ore processing operations (phosphate rock) fall under the temporary mining waste exemption of 40 CFR 261.4(b)(6). However, the properties of these wastes are such that, if not for the exemption, the wastes would be considered hazardous by virtue of their corrosive nature.

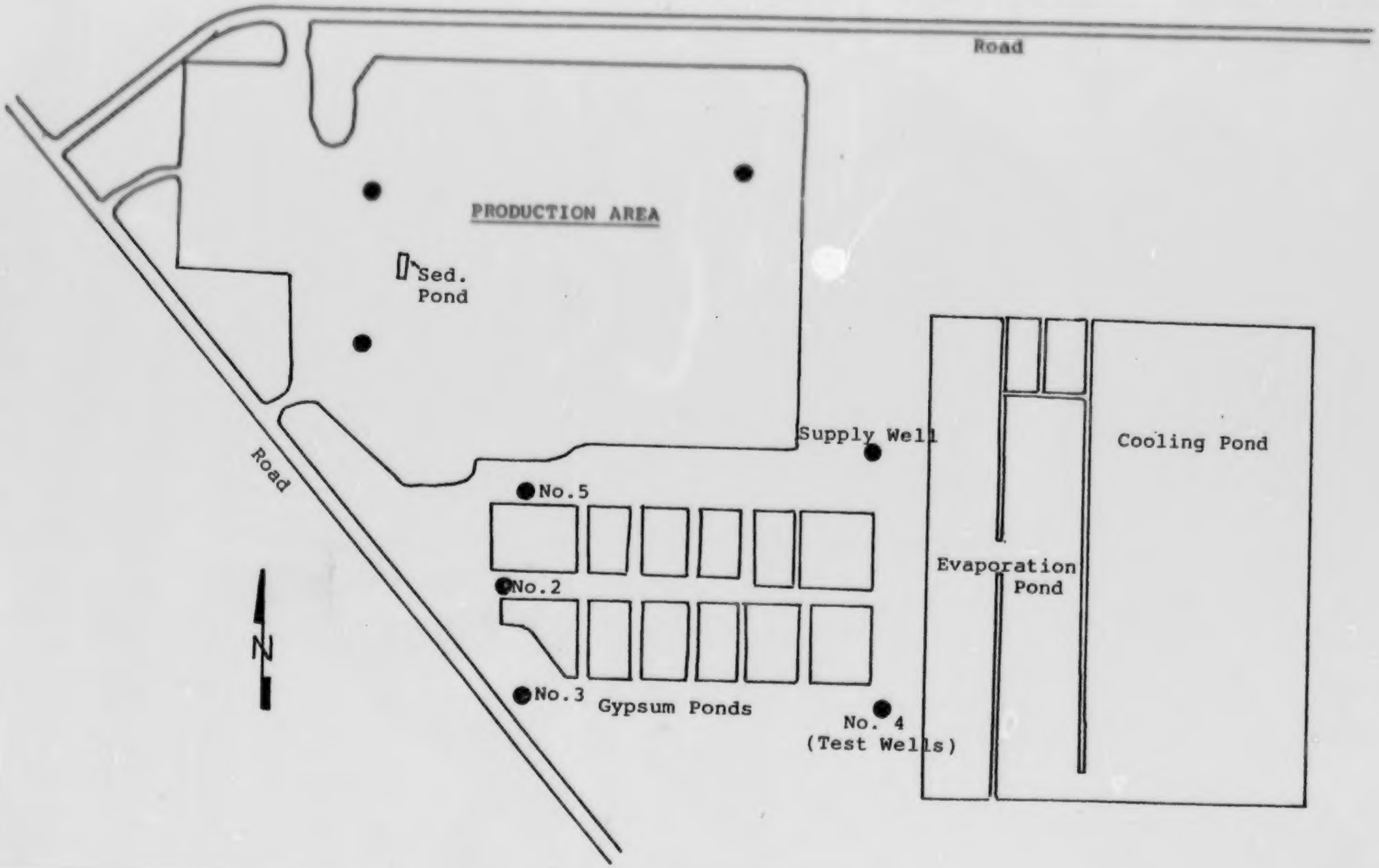
Road
PRODUCTION AREA
Sed. Pond
Supply Well
Cooling Pond
Evaporation Pond
No.5
No.2
No.3
Gypsum Ponds
No. 4
(Test Wells)
Road
N

Figure 3. Plant Layout

taking into account the results and recommendations of three engineering studies.

First, as a part of a sulfuric acid plant expansion, a private consulting firm prepared a geologic-seismic study in September 1974. Three months later, this same firm conducted a soils investigation of the site in connection with a proposed phosphate plant addition. The report described the soil conditions observed in 43 test borings drilled in the area of the proposed plant, evaporation pond, and cooling pond. The report also contained recommendations for the design of the evaporation and cooling ponds. Finally, an environmental impact report was prepared for the phosphate plant expansion (including the cooling and evaporation ponds). The results of these studies are discussed in Sections 4.4 and 4.6.

3.0 DESIGN, CONSTRUCTION, AND INSTALLATION FIRMS UTILIZED

The owner has no information as to when the unlined sedimentation pond was put into service, or who designed and constructed it.

All of the gypsum ponds were designed by the owner and constructed by a local private contractor.

After consulting a number of engineering firms and liner manufacturers, the owner designed the evaporation and cooling ponds and wrote liner specifications. Reinforced EPDM (ethylene propylene diene monomer) used on the side slopes of the evaporation and cooling ponds was manufactured by Carlisle Tire and Rubber Company. PVC (polyvinyl chloride) sheeting for the bottom of each pond was manufactured by the Pantasote Company and fabricated by Watersaver Company. All liners were installed by a large installation contractor.

4.0 DESIGN CRITERIA

4.1 Purpose of the Surface Impoundments

The purpose of the sedimentation pond is settling of solids in the blowdown from hot lime treaters. Production water generated during descaling and flushing of process pipeline is occasionally routed to the gypsum ponds for settling and recovery of gypsum. The evaporation pond is used for storage of wastewaters for recycle back into the phosphoric acid plant. Process waters are cooled in the 38-acre cooling pond.

4.2 Waste Characteristics

The lime sedimentation pond receives about 16,000 gallons per day of blowdown water from the hot lime treaters. The blowdown is a calcium and magnesium carbonate slurry with the following characteristics:

Constituent	Value
E.C., μmhos/cm	700 - 4000
pH	7.5 - 9.0
TDS, mg/1	800 - 2400
SO_4, mg/1	220
Ca, mg/1	35
Na, mg/1	300

Production water from the ammonia phosphate/phosphoric acid plant is intermittently routed to the gypsum ponds for settling of solids (the average flow to these ponds is approximately 20,000 gallons per day). The evaporation pond receives about 40,000 gallons per day of blowdown water and runoff water. The cooling pond recirculation rate is approximately 10,000 gallons per minute. This pond has an inflow of 130,000 gallons per day of production water. The inflows to both the evaporation and cooling ponds contain rainfall and runoff. The process pond water demands exceed the inflows to the evaporation and cooling ponds such that fresh water must be added to maintain minimum pond levels.

Major wastewater constituents found in all of these ponds include ammonia, organic nitrogen, nitrate, phosphorous, sulfate, chloride, cadmium, calcium, iron, magnesium, potassium, sodium, zinc, fluoride, aluminum, algicides, oil and grease, surfactants, polymers, and radioactive species. The pH, solids content, and radioactivity of wastewaters from these ponds are as follows:

Constituent	Gypsum Ponds	Evaporation Pond	Cooling Pond
TDS, mg/1	37,900 - 77,700	21,600 - 39,400	22,800 - 42,800
pH	1.6 - 2.1	1.5 - 1.9	1.3 - 1.7
Gross Alpha, pCi/1	1,590 - 5,260	2,720 - 4,260	2,560 - 5,070
Gross Beta, pCi/1	1,710 - 5,060	2,260 - 2,810	2,300 - 3,250

4.3 Service Life

Subject to several provisions, the manufacturers of the EPDM and PVC used in the evaporation and cooling ponds warrant a 10-year minimum useful life on the liner material.

4.4 Site Hydrogeology

The hydrogeology of the area in the vicinity of this facility was studied in 1974 and 1975 in conjunction with plant expansions. The following hydrogeological description of the plant site is based on these studies.

- **Evaporation Rate**: 63.5 inches per year.

- **Precipitation**: 7.44 inches per year.

- **Temperature**: Varies from a mean of 44.3°F in the winter to a mean of 81.1°F in mid-summer. Freezing nighttime temperatures can occur from mid-November to mid-February.

- **Surface Water Conditions**: A nearby slough, located immediately north of the plant, provides a link between two other sloughs which empty into a large river. All of these sloughs return flow from irrigated lands during the irrigation season. Local storm runoff in the winter months also drains into these sloughs. Present-day flood control system essentially precludes the potential of flooding at this site.

- **Groundwater Conditions**: Three distinct groundwater bodies occur in the fertilizer plant area: (1) an upper aquifer (unconfined and semi-confined fresh water which occurs in alluvial deposits of Recent and Pleistocene age overlying a clay aquitard); (2) a lower aquifer (fresh water confined beneath the clay aquitard in alluvial and lacustrine deposits of late Pliocene age); and (3) a body of saline connate water contained in marine sediments of middle Pliocene or older age. In addition to these water bodies, a perched or semi-perched water body may exist above the clay layers.

  The base of fresh water in the area lies at about 1000 feet in depth. Well depths generally range between 200 and 600 feet. Nearly all of the wells tap only the upper aquifer, although some shallow domestic wells may pump perched water. A number of irrigation and domestic wells surround the plant site, particularly to the southwest and northwest. The average depth to water in the area is about 130 to 150 feet. Depth to water under the plant was 122 feet in 1975. Recharge to the upper aquifer is by return flow of excess applied irrigation water, canal and river seepage, and groundwater inflow from the northeast. The direction of movement of groundwater in the upper aquifer in the plant area is apparently to the southwest. Since the site is located between surface water bodies which may contribute to recharge water, it appears that the groundwater flow gradient in the perched zone will be nearly flat and directed slightly towards the north. Little data are available on hydraulic heads in the lower aquifer.

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*These small unlined ponds, approximately 10 feet deep, were utilized as a holding pond for waste lubricating oil and a percolation pond for "waste-water". They were removed in 1975; no other data are available on these ponds.

Test holes bored on site encountered free water at about 30 feet in test holes adjacent to two old waste disposal ponds (now covered)* and at a depth of about 50 feet at a distance of several hundred feet from these ponds. Test holes of the U.S. Bureau of Reclamation in nearby sections have also encountered perched water, probably from the return flow of excessively applied irrigation water.

- Geology: The plant complex is located in a valley with a topographically low plain that contains a great thickness of sedimentary rocks and recent alluvial sediments. Beneath the plant location, these sediments are approximately 11,000 feet thick and overlie Mesozoic igneous and metamorphic rock.

  There are no known faults or shear zones extending through the site which will endanger structures due to differential, horizontal or vertical movement. The potential for strong motion earthquake activity in the general area, based on past history, is low. Soils such as found beneath this site are unlikely to liquefy under the maximum earthquake accelerations anticipated for this site; hence, the possibility of liquefaction occurring at this site is extremely low.

4.5 Waste-Liner Compatibility

Although the owner's liner specifications required testing of all liner material with a specified solution similar to that of the actual effluent, no such test results were available. Acceptance tests on the PVC and scrim reinforced EPDM liner materials were performed in accordance with the fertilizer company's liner specifications, with modifications to reflect industry standards and methods (for comparative purposes) by an independent testing laboratory. Acceptance tests included the following: elongation, dimensional stability, coefficient of permeability, alkali resistance, pinholes and cracks, bonded seam strength, thickness, specific gravity, acid resistance, volatility, tensile strength, and modulus.

Both materials complied with the modified specification requirements on all tests performed. Note that the acid resistance test was performed at a pH of 3, while the pH of the wastewater typically is less than 2. Furthermore, these acceptance tests are standard liner industry tests which are short-term and do not predict long-term performance.

4.6 Soil Permeability

Soils beneath the sedimentation pond and gypsum ponds were not characterized prior to construction.

Based on 16 test borings drilled in the cooling and the evaporation pond areas by a geotechnical consultant, the soils beneath the ponds can be generalized into two categories. The near surface soils are generally cohesive, composed primarily of silts and clays. The clay has a high calcium carbonate and low soluble sulfate content. Beneath the cohesive material, a clean sand is encountered which extends to a depth of 30 to 50 feet. Some silt layers and lenses, 3 to 7 feet thick, are noted within the sand at a depth of 20 to 30 feet and again at about 50 feet.

Test borings indicate that the cohesive surface material is absent at the extreme north end of the ponds with the thickness rapidly increasing southward. The thickness of the cohesive layer is generally 5 to 6 feet, but ranged from 0 to 8 feet at the boring locations.

Tests indicate that the in-place cohesive layer has a relatively low permeability on the order of 10^{-6} centimeters per second in its native condition. When compacted, this material has a permeability on the order of 10^{-7} centimeters per second. The permeability of the underlying sand ranges from about 10^{-2} centimeters per second to 10^{-4} centimeters per second.

Because the surface cohesive soils were expected to react with some of the chemicals produced by the plant and because of the soil expansion potential and the greater potential for compression due to foundation loads, the consultant recommended that the cohesive soil not be used as fill beneath the new plant structures. (A combination of the chemical reaction and swelling of the clay was expected to cause heaving of foundations.) However, regarding the evaporation and cooling ponds, the consultant recommended the following:

> "A layer of the cohesive soil will be needed over the entire base of the pond area in order to assure water retention in the ponds. Based on our laboratory permeability tests, we conclude that the on-site cohesive soils will provide a suitable lining for the ponds when properly compacted. It is our opinion that where the cohesive soil is presently in-place, a lining can be constructed by scarifying and compacting the in-place materials. Where the cohesive material is absent or where borrowing operations within the pond areas have eliminated the cohesive layer, a lining may be constructed by placing materials imported from other areas of the site ... Pond embankments should be constructed of the cohesive soils in order to provide satisfactory stability, to maintain continuity of the liner, and to resist wave erosion."

4.7 Regulatory and Permit Requirements

Wastewater discharge requirements, first ordered by the state in 1959, permitted the owner to discharge plant blowdown effluent (within certain concentration limits) from fertilizer synthesis to a nearby slough*. In 1964, the owner requested and received a relaxation of wastewater concentration limits because the receiving waterway had been dammed above and below the point of discharge to preclude the use of the slough for fishing. It was a combination of federal water pollution control regulations and the plant expansions of 1974 and 1976 that provided the impetus for the construction of the evaporation and cooling ponds.

In 1976, a revised permit was issued for the facility by the state. Specific requirements addressed by the state included the following:

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*This waste stream is currently discharged to the lined evaporation pond. The discharge of plant wastewater to the slough was halted in June 1977.

- The discharge of plant blowdown to the slough shall not exceed 600,000 gallons per day and have maximum daily TDS content of 1,750 mg/l. Upon completion of the evaporation pond and no later than 30 June 1977, discharge to the slough is prohibited.
- Discharge to the sedimentation pond shall not cause degradation of any water supply.
- The discharge of liquids to gypsum ponds not rendered impervious to percolation is prohibited. Discharger shall demonstrate compliance to this provision within 90 days.
- The evaporation and cooling ponds are to be rendered impervious to percolation by the use of a synthetic membrane.
- The facility shall be protected from inundation by a 100-year flood.

In 1978, the permit was updated, and the following changes in requirements were made:

- The discharge of liquids to all ponds shall not cause degradation of any water supply. The electrical conductance of lime treater wastewater shall not exceed 1200 micromhos. Discharges to the gypsum, evaporation, and cooling ponds shall be confined to ponds determined to be impermeable.

In addition, there are requirements for a self-monitoring program which includes effluent, receiving water, and groundwater monitoring and reporting.

4.8 Cost Considerations

No data are available on consideration of costs as criteria in design (e.g., liner or contractor selection).

5.0 DESCRIPTION OF DESIGN AND DESIGN SPECIFICATIONS

5.1 Sedimentation Pond

This 1.0 acre unlined pond receives a calcium and magnesium carbonate slurry from hot lime treaters. The sludge is dredged out and recycled on a yearly basis. No other information on this pond is available.

5.2 Gypsum Ponds

Production water is discharged to these unlined ponds intermittently for settling solids. The ponds cover 14 acres and are divided into 11 areas plus a holding pond. Currently, production water is directed to ponds 5 and 6 and then to ponds 10 and 11 about one or two days per month. The ponds were constructed over a period of years, starting in the mid-1960's. All ponds were in service intermittently until March 1980 when the current operating mode was established.

The ponds were constructed by a local contractor by scarifying and compacting in-place soils and forming embankments. No detailed data are available on construction techniques or quality assurance/quality control (QA/QC) procedures used.

Although there are several domestic, company, and agricultural water supply wells surrounding the plant site, groundwater monitoring is not performed. However, in 1976, five test wells were drilled around the gypsum ponds in order to determine whether or not the ponds were leaking. The wells were sampled weekly for a time; the results are discussed in Section 7.1.

5.3 Evaporation/Cooling Ponds (See Figure 4)

The bottom of the evaporation and cooling ponds is lined with approximately 1.6 million square feet of 12-mil polyvinyl chloride (PVC) plastic liner. The embankment slopes of both ponds are covered with 302,652 square feet of Dacron scrim reinforced ethylene propylene diene monomer (EPDM) material with a thickness of 30 mil. The two small settling ponds adjoining the northwest corner of the cooling pond are lined (bottom and slopes) with concrete.

Prior to placing the FMLs, the side slopes and bottom of both ponds were covered with a one-foot layer of in-place clay compacted to 95 percent of Standard Proctor. Thus, the surface underneath the synthetic liners should be generally smooth and free of sharp objects. Packages of PVC were inspected on site by two company engineers for evidence of penetration or damage due to folding. Damaged material was either repaired or rejected. The FMLs were protected from wind billowing during installation. The EPDM was installed first to ensure easy access to vertical field seams. The EPDM was placed on top of the PVC to make a 6-inch horizontal seam at the toe of the embankment (not on the slope). Field seams, factory seams, and patches were randomly vacuum leak tested by a fertilizer company representative. The installer used seam adhesives that were recommended by the liner manufacturers. Immediately after the liners were installed, two feet of water was placed in the ponds to protect the PVC bottom from environmental exposure.

The top edge of the liner was anchored by a trench 12 inches deep and 8 inches wide. The trench was backfilled and compacted to 90 percent of Proctor. All embankments have 3:1 slopes.

Both ponds have a leak detection system consisting of a "V" ditch compacted to 95 percent of Standard Proctor, a 3-inch diameter perforated drain pipe, a 9-inch layer of gravel, a 9-inch layer of sand, a catch basin, a 4-mil polyethylene gravel cover, and a 30-mil PVC bottom layer (see Figure 5). The evaporation pond has three "V" ditch drains along the length of the pond extending almost entirely across the pond's width. The cooling pond has four long "V" ditch drains. All drains have a 0.25 percent slope towards their respective catch basins.

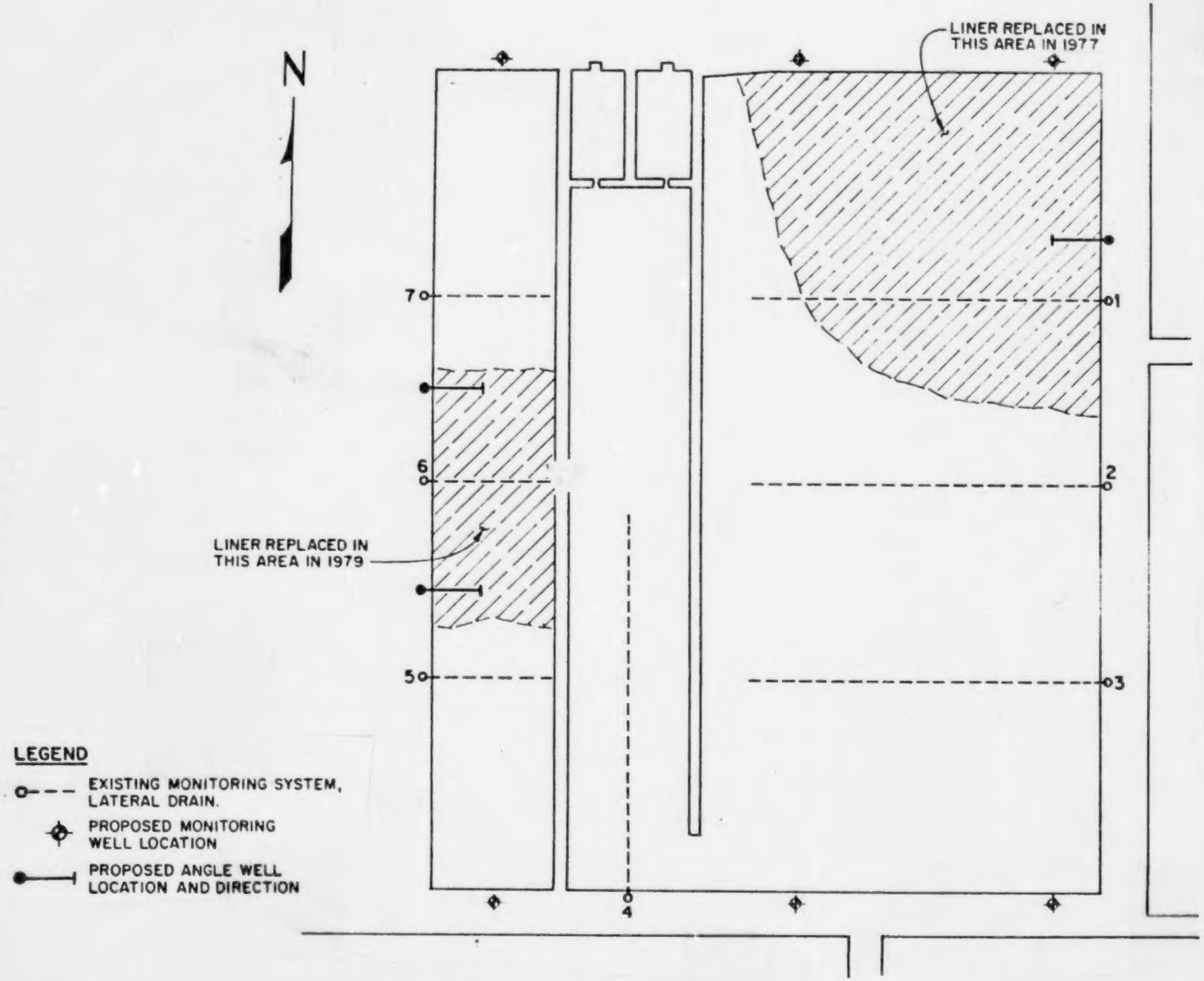
N
LINER REPLACED IN THIS AREA IN 1977
LINER REPLACED IN THIS AREA IN 1979
1
2
3
4
5
6
7
LEGEND
EXISTING MONITORING SYSTEM, LATERAL DRAIN.
PROPOSED MONITORING WELL LOCATION
PROPOSED ANGLE WELL LOCATION AND DIRECTION

Figure 4. Layout of Evaporation/Cooling Ponds

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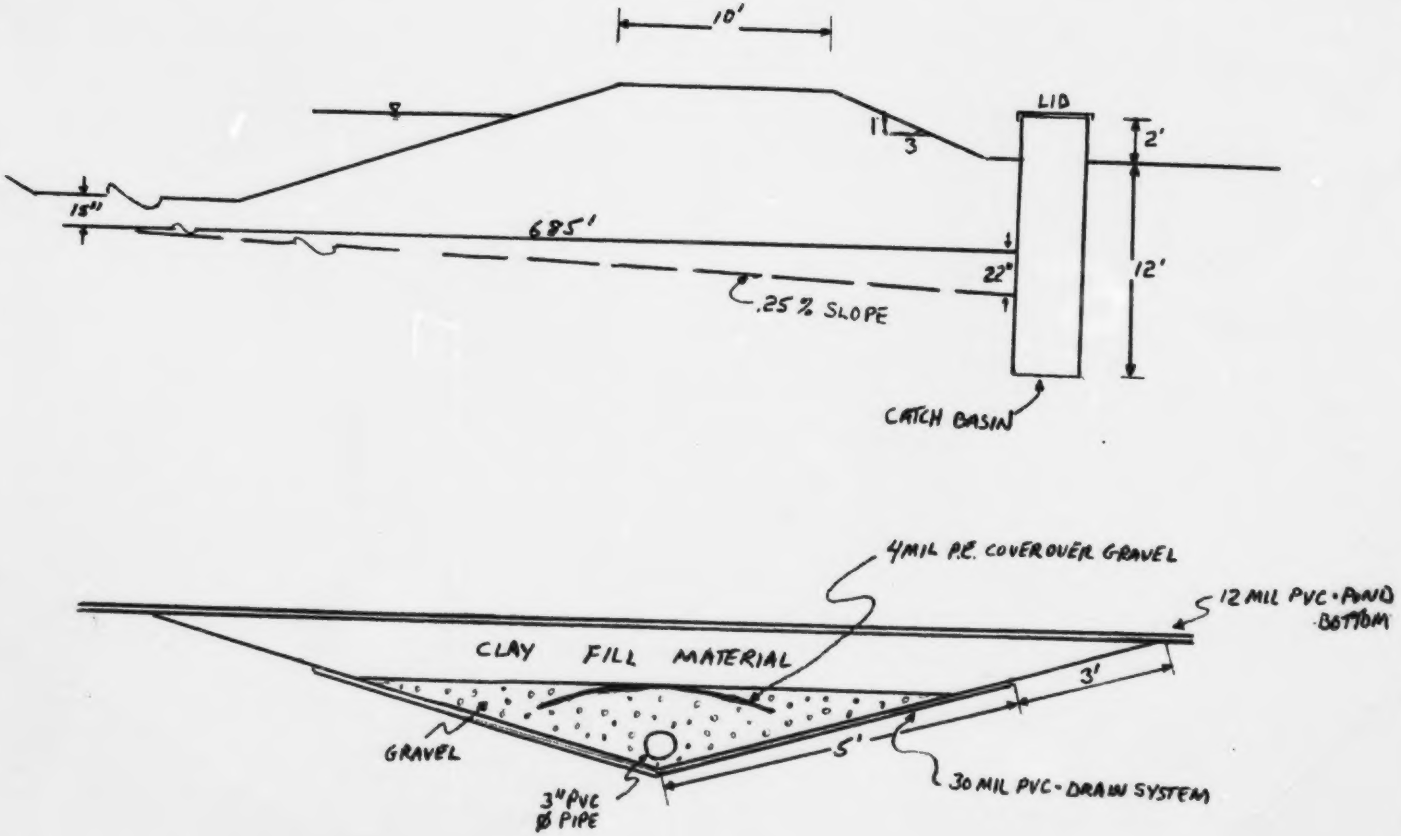
10'
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2'
1
3
12'
15"
685'
22"
.25% SLOPE
CATCH BASIN
4MIL P.E. COVER OVER GRAVEL
12 MIL PVC • POND BOTTOM
CLAY FILL MATERIAL
3'
5'
GRAVEL
3" PVC Ø PIPE
30 MIL PVC - DRAIN SYSTEM

Figure 5. Leak Detection System Details

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(4-76)

The leak monitoring wells (catch basins) are labeled 1 through 7 on Figure 4. Seepage, if any, from the wells is sampled and analyzed on a monthly basis for phosphate and sulfate content, pH, and electrical conductance.

A company engineer was on site at all times during the construction of the evaporation and cooling ponds. Although there was no QA/QC recordkeeping, the company wrote several specifications and requirements for QA/QC in connection with securing and installing the synthetic liners (see liner construction specifications, Appendix B). These specifications included:

- Prior to installation, the contractor shall inspect the foundation surface and advise the company, in writing, that the surface is adequate and ready for the liner.
- Liner material will be tested prior to delivery and marked so that the company can be assured that liners tested are the actual liners installed.
- All field and factory seams will be randomly tested as designated by the company engineer.
- Contractor will verify, in writing, that the material and adhesive used for the drain pipe will withstand the specified pond chemical compositions and burial pressures imposed by the soil, in accordance with detailed drawings.

6.0 DEVIATIONS FROM DESIGN, PROBLEMS ENCOUNTERED DURING CONSTRUCTION, AND COSTS

No data are available on modifications to the original plans, problems during construction, and costs of the sedimentation and gypsum ponds.

6.1 Cooling/Evaporation Ponds

Original design specifications for these ponds were modified two times during site development. As recommended by the geotechnical consultant, the original plans called for a continuous layer of homogeneous cohesive soil (clay liner) placed on the bottom and side slopes of each pond. The cohesive soil was to be 12 inches thick, placed in 6-inch lifts, compacted to 95 percent of Standard Proctor density, and have a permeability of 10^{-7} cm/sec. After the clay liner was installed, design specifications for a synthetic liner were drawn up by the company because of possible degradation of the clay soil by the acid wastes that it contained, and because soil tests indicated that the clay liner permeability was greater than 10^{-7} cm/sec in certain areas of the ponds. Furthermore, several local agencies were opposed to the clay liner and advocated the use of a plastic liner as suggested in the environmental impact report.

For reasons which are not documented, the first set of FML specifications were slightly modified. The following is a list of the changes made to the liner specifications:

- Pond slopes lined with 30-mil EPDM were originally to be lined with 35-mil chlorinated polyethylene (CPE).
- The two small concrete settling ponds adjoining the cooling pond were originally to be lined with 30-mil PVC.
- Vacuum testing of factory and field seams was modified to also include patches made during the original installation.
- The chemical solution used for waste compatibility tests on leachate monitoring system materials was expanded to include one percent organics.
- Filling of ponds after liner installation was changed from 2 inches of water to 2 feet of water.

The engineer who observed the installation of these ponds is no longer with the company so that problems encountered during construction could not be identified.

The initial cost of these ponds, including the original excavation, clay lining, and the subsequent membrane lining installation was $1,450,000 (1976 dollars).

7.0 PERFORMANCE DATA AND OPERATING EXPERIENCE

Since there are no groundwater monitoring wells or leak collection/detection systems for the sedimentation pond and no pond studies have been conducted, the performance of this pond cannot be assessed. Because of the types and quantities of wastewater constituents this pond contains in comparison with the other impoundments, the potential for this pond to pollute ground or surface waters is considered insignificant.

7.1 Gypsum Ponds

In March 1976, the first wastewater discharge permit was issued by the state to the company. In this permit, the state prohibited the company from "the discharge of liquids to facilities (gypsum ponds) not rendered impervious to percolation". To provide information to determine compliance with this prohibition, the company set up four test wells along the perimeter of the ponds (see Figure 3). The well screens ranged from about 20 to 60 feet in depth. Samples collected over a one-month period were analyzed for pH and sulfate content. The results are summarized in Table 23. For reasons which are not documented, the data proved inconclusive to state personnel.

About three months later, 6 soil cores were taken around the gypsum ponds and at two locations, 500 feet and 1500 feet south of the plant. Soil core samples taken at various depths were analyzed for sulfate content and pH. The results are presented in Table 24. Apparently, the soil core test results were unsatisfactory to state personnel in demonstrating compliance with the "impervious" prohibition because the company subsequently hired a

TABLE 23. GYPSUM PONDS TEST WELL ANALYTICAL RESULTS

Well No.	Sample Date	pH	PPM SO_4
2 S	8-17-76	2.9	7,200
2 S	8-26-76	2.9	17,600
2 S	8-31-76	3.1	10,500
2 S	9-09-76	3.1	13,600
2 S	9-16-76	3.1	13,400
2 S	9-22-76	3.3	13,400
2 D	8-17-76	5.6	10,500
2 D	8-26-76	5.6	18,800
2 D	8-31-76	5.7	16,400
2 D	9-09-76	5.6	18,800
2 D	9-16-76	5.6	17,800
2 D	9-22-76	5.7	10,200
3 S	Checked on 8-12-76, 8-19-76, 8-27-76, 9-4-76, 9-16-76, and 9-20-76. Dry in each instance.		
3 D	8-12-76	6.3	6,320
3 D	8-19-76	5.8	5,000
3 D	8-27-76	5.8	10,800
3 D	9-04-76	5.8	12,800
3 D	9-10-76	5.9	8,600
3 D	9-17-76	5.8	15,200
3 D	9-24-76	5.8	10,400
4 S	8-06-76	Dry	
4 S	8-16-76	Dry	
4 S	8-25-76	Dry	
4 S	9-14-76	8.0	1,700
4 S	9-20-76	Dry	
4 D	8-06-76	8.2	462
4 D	8-16-76	Dry	
4 D	8-25-76	Dry	
4 D	9-14-76	7.7	1,200
4 D	9-20-76	7.5	1,200
4 D	9-24-76	8.1	1,370
5 S	Checked on 8-10-76, 8-18-76, and 9-14-76.		
5 D	Dry in each instance.		

TABLE 24. ANALYTICAL RESULTS OF SOIL CORES TAKEN AROUND THE GYPSUM PONDS

	Sample Identification (mg/l)					
	A	C	D	E	F	H
Depth	pH	pH/SO_4	pH/SO_4	pH/SO_4	pH	pH
0				7.7/383	8.2	
1	8.2		7.2/1210			
5	8.3		8.9/350	8.3/245	8.0	
10	8.5		8.7/318	8.4/260	8.2	
15	8.2		8.6/660	7.8/158	7.6	
20	8.2		8.0/660	7.6/195	7.7	
25	8.0	8.1/238	8.1/730	/132	8.6	
30	8.3	7.1/1840		8.3/175	8.5	
35	8.4	7.7/990	7.8/1260	8.2/138	8.4	
40	8.5	7.8/1390		8.0/190	8.1	
45	8.5	7.8/1480		8.1/105	8.1	
49		6.7/3285				
50	8.5	6.4/4850		8.2/43	8.3	
55	8.3			8.1/95		6.7
60	8.5			8.1/53		
65				8.4/84		
70	8.4			7.9/53		
75						7.1
80	8.3					

consultant to perform test drilling and core sampling in the bottom of one of the gypsum ponds.

Five borings were extended to depths of 8.5 to 9 feet in the bottom of pond 8. core samples were taken in only one pond to minimize the risk of creating permeable zones caused by the drilling. In general, gypsum cemented sand was encountered from the surface to a depth of about 5 to 7 feet. This material was extremely hard and rig modifications were required for drilling and sampling. In the 5 to 7 feet depth range, a transition zone was encountered; below this level, native sands with varying amounts of gypsum cemented lumps were encountered to the total depths drilled. Free water was encountered in 3 of the 5 borings at depths of 5 to 5.5 feet. Previous drilling experience adjacent but outside the ponds indicated groundwater at depths greater than 30 feet.

Four-inch diameter core specimens of the hard surface gypsum materials were obtained and sent to the laboratory for permeability testing. All samples appeared relatively uniform, consisting of highly cemented silty, fine to medium sand. Core samples 2.2 inches in diameter were taken from the 4-inch diameter cores and tested for permeability, using the falling head method. The permeabilities of the core samples ranged from 4×10^{-5} to 2×10^{-6} cm/sec. Based on this information, the state ruled that the gypsum ponds "are impervious due to the natural buildup of gypsum in the ponds".

The gypsum ponds are dredged every other year by a local contractor. The contractor uses bulldozers and motorgraders to remove the gypsum form the ponds. The owner states that the bottoms of the gypsum ponds are extremely solid; hence, there is little chance of disrupting the gypsum cemented impermeable layer.

In order to "determine what effect, if any, the disposal operation has on underlying ground water", the state recently ruled that two ground water monitoring wells be placed upgradient and downgradient of the gypsum ponds.

7.2 Evaporation/Cooling Ponds

The PVC-EPDM liners were installed in May of 1976 and soon afterwards began to receive plant wastewaters. On 9 August 1977, state inspectors discovered several plastic liner bubbles in the cooling pond (this was apparently the result of contact between the acid waste and the calcium carbonate clay soil under the FML). At the time of the inspection, the liner bubbles were being collected into a large bubble where a valve would be placed to release the air and lay the liner flat on the bottom with the valve closed to facilitate repair. Repairs were made at the northeast corner of the cooling pond in October 1977 by partially draining and sandbagging the pond (see Figure 5). The total cost for replacing that part of the liner was $197,000.

On 20 September 1978, state personnel made an inspection because leak detection wells at the evaporation pond had recently indicated a leak in the liner. At the time of the visit, the pond was empty and the liner was being repaired. As with the cooling pond, liner bubbles were noted (by the owner) in the pond. Repairs to the evaporation pond liner made by the installer cost $50,000. Also during this inspection, one of the leak detection wells indicated the existence of another leak in the cooling pond liner.

In order to stop the new leak in the cooling pond, some gypsum slurry was added to the pond in hopes that the leak would be sealed by the same reaction mechanism that had rendered the gypsum ponds impermeable. After two months, the company reported to the state that the leak had stopped.

Both conventional repairs and that made by adding gypsum were short-lived. Based on monitoring data from leak detection well No. 1 (for the cooling pond) and leak detection well Nos. 5, 6, and 7 (for the evaporation plot of pH of the leakage collected in these four detection wells versus time is provided in Figure 6. In general, the data show that the liquid consistently has a pH value very close to that of the incoming waste. The composition of the liquid being collected by leak detection well No. 5 is obviously being influenced by some outside source.

Because both ponds have been leaking for some time, the state requested the discharger to: (1) submit plans and time schedule for repairing leaks, and (2) submit a technical report containing plans to construct a ground water monitoring system. The owner has proposed a program to address the leaks in three phases:

- A groundwater monitoring system is proposed with peripheral wells and slant wells below suspected leakage areas to define migration from the ponds. Systems to measure flow rates into the leak detector basins will also be installed.
- Groundwater monitoring wells will be sampled quarterly for pH, sulfate, conductivity, phosphate, and radionuclides. Leakage rates into leak detection basins will be measured and recorded.
- The collected data will be analyzed with the impact determined and correction plan developed, if necessary.

The slant wells could encounter evidence of leakage in the zone above the perched water table where the vertical wells may not. Lateral movement in the perched aquifer, however, would be detected if a plume of high TDS fluids passes through the monitoring well locations. Movement of this plume (if any) can be expected to take months or years to show in the wells.

The EPDM liner on the slopes of both ponds has held up much better than the PVC bottom liners. There has been an instance or two of mechanical damage and wave erosion problems have occurred at the southeast corner of the evaporation impoundment, but has been corrected with sand bags.

The cement settling ponds adjoining the northwest corner of the cooling pond are dredged with a payloader several times each year by a local con-

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*Although water was observed in leak detection well No. 3 during a state inspection on 31 March 1982, no analysis data were provided in the corresponding monthly company report.

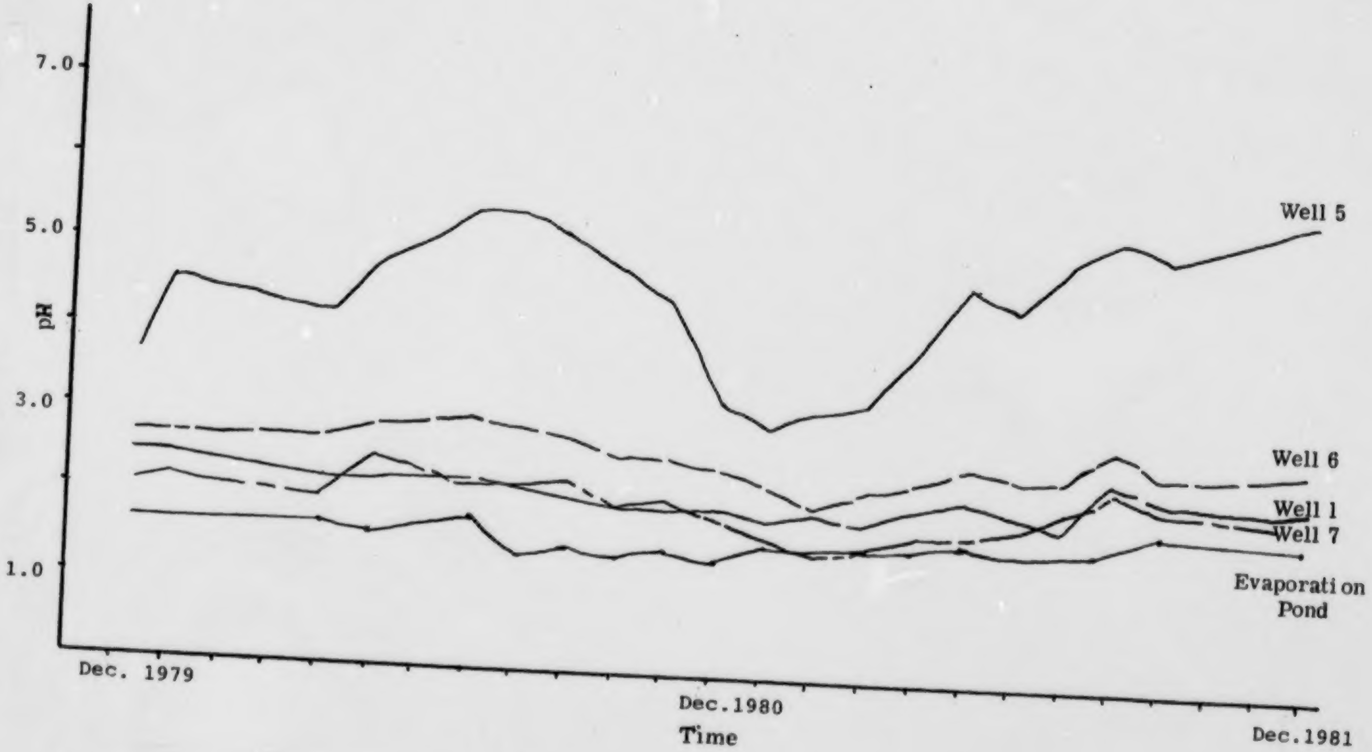

Figure 6. pH of Leakage in Wells Over Time

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tractor. The evaporation pond has only been dredged once, while the cooling pond has never been dredged. The narrow channel of the evaporation pond was dredged in 1981 using mud cats to scoop up the gypsum sludge. There was a company engineer on site to make sure that the contractor did not damage the liner. Using water level markers, the engineer restricted the contractor from dredging less than one foot from the bottom of the pond.

REFERENCES AND DATA SOURCES

1. Wastewater discharge requirements, 1978.
2. State inspection reports for 1977-1978, and 1982.
3. Self-monitoring reports, 1980-1982.
4. Soils Investigations, Proposed Phosphate Plant Additions, 1974.
5. Draft Environmental Impact Report, 1975.
6. Miscellaneous correspondence between owner and state.
7. Discussions with the facility production manager, June 1983.

CASE STUDY NO. 5

1.0 GENERAL DESCRIPTION AND HISTORICAL BACKGROUND

This mineral ore mining, milling, and processing plant is located in a desert region of the Southwest. Plant operation began at the site in 1926, but wet processing of ore did not commence until 1956. The major waste streams consist of solid materials (overburden and gangue) which are trucked to on-site piles and liquid waste slurries which are disposed of in clay-lined surface impoundments. The mine/mill/disposal area complex is located on a 3,000+ acre site surrounded by undeveloped desert.

Native soils at the site consist mainly of permeable alluvial materials. However, deposits of low-permeability clay have been found in mine workings and in a nearby dry lake which are suitable for pond liners. Ground water at the site is encountered at 140 to 160 feet below the surface and contains about 500 to 1,500 mg/l total dissolved solids. Surface water is only present as runoff during and immediately after rainstorms. Rainfall averages 4 to 6 inches annually.

Tailings slurries from the main refinery ore processing operations are disposed of in surface impoundments. Figure 7 is a diagram of the tailings pond system. Ponds 1, 2, and 3 are unlined tailings ponds which were

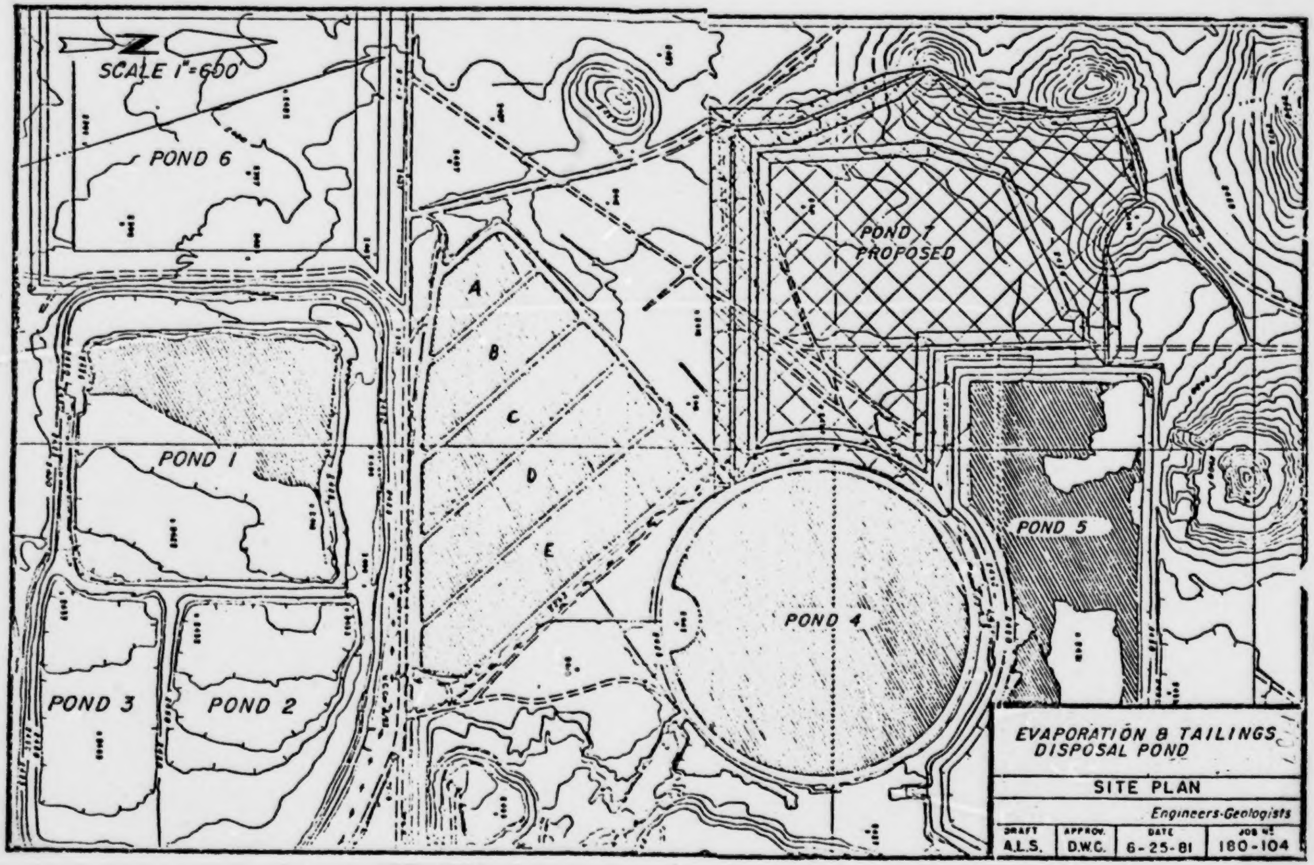
SCALE 1"=600'
POND 6
POND 7 PROPOSED
A
B
C
D
E
POND 1
POND 2
POND 3
POND 4
POND 5
EVAPORATION & TAILINGS DISPOSAL POND
SITE PLAN
Engineers-Geologists
DRAFT A.L.S.
APPROV. D.W.C.
DATE 6-25-81
JOB No. 180-104

Figure 7. Evaporation and Tailings Ponds

abondoned in 1975.* All other ponds are clay lined. Tailings from the plant are pumped to Pond 5 (built in 1976) where they settle out. Clear tailings solution is decanted from this pond to Pond 4 (built in 1975), the old tailings pond. Pond 4 is now full of tailings and acts only as a solar evaporation pond. Overflow from Pond 4 is sent to low-head solar evaporation Ponds A through E (built in 1972). Clear solution from these ponds is recycled to the plant for use in a wet scrubber. Pond 7 is to be operational and accepting tailings from the main plant in February, 1985. Pond 6 (built in 1980) accepts tailings from the mineral acid plant. Separate disposal for these wastes is necessary because mixing of the tailings will result in: (1) difficult recovery of tailings, (2) unsuitability of clarified liquid as a scrubber medium in the acid plant. High pH liquid (pH 9.2 to 9.5) from the solar evaporation ponds may be used to neutralize acid plant waste (pH 3.2 to 3.3) prior to disposal in Pond 6.

2.0 BASIS FOR SITE SELECTION

All active ponds were located on site based on the results of feasibility studies conducted by a geotechnical consulting firm. The studies included site inspection, test borings, laboratory testing (grain size distribution, density, shear strength, compaction, and permeability of field compacted and laboratory remolded samples using actual wastewater solutions), and engineering analysis. A draft environmental impact report was also prepared for Pond 6.

3.0 DESIGN, CONSTRUCTION, AND INSTALLATION FIRMS UTILIZED

All ponds were designed by the same geotechnical consultant in cooperation with the owner/operator. Ponds A-E were constructed by the owner's mining department using mining and rental equipment. The construction was supervised and inspected by the geotechnical consultant. Ponds 4, 5, and 6 were constructed by three very large contractors and supervised and inspected by the geotechnical consultant.

4.0 DESIGN CRITERIA

4.1 Purpose of Impoundments

The purpose of Ponds A-E, 4, and 5 is treatment of tailings slurries from the refinery via storage of solids and evaporation of water. Pond 6 is used to evaporate water and store acid plant tailings.

4.2 Waste Characteristics

Wastes generated as a direct result of mining and ore processing operations fall under the temporary mining waste exemption of 40 CFR 261.4 (b)

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*Except where noted, the design and performance of these abondoned tailings ponds will not be discussed.

(6). Therefore, the major wastes produced at the plant are not hazardous wastes whose disposal is regulated by RCRA regulations. However, the properties of these wastes are such that, if not for the exemption, the wastes would be considered hazardous by virtue of their arsenic content. The process which generates these wastes involves dissolving the mineral ores and removing the clay impurities (gangue). Water (and sulfuric acid in the acid plant) is used to dissolve crushed ore. The larger particles of clay stone remaining (sands) are removed by screening the dissolved mineral liquor. Screened-out gangue is then disposed of in waste dumps. The remaining undissolved clay material occurring as slimes is separated from the pregnant liquor by countercurrent decantation in thickeners. Thickener underflow consists of a tailings slurry which is impounded. Arsenic and boron content of the tailings liquor (as discharged to the ponds) is in the 50 to 100 ppm range and 2,000 to 4,000 ppm range, respectively. Acid plant tailings (as discharged to Pond 6) contains approximately 20 ppm arsenic and 3,000 to 8,000 ppm boron. A total monthly discharge of 50 million gallons to the tailings ponds and 12 million gallons to Pond 6 is typical.

4.3 Service Life

The service life of each pond is based on a "zero leakage concept" developed by the geotechnical consultant and approved by the state regulating agency. The concept involves lining each pond with compacted clay and then calculating from the clay thickness and permeability, as well as the liquid head to be imposed, the number of years it would take for the waste liquor to reach the bottom of the clay liner and be intercepted by the leak detection system. Once leakage is detected by this system, the pond is to be drained and placed out of service.

Based on the results of a large number of laboratory permeability tests, a design permeability of 2×10^3 feet per year (2×10^{-9} cm/sec) and an effective porosity of 0.45 were considered applicable for all clay lined ponds. For fixed soil properties, pond life is a function of seal layer thickness and total pond head. Calculations using the above design permeability and porosity provide the time required for the pond fluid interface to pass through the clay liner as illustrated in Figure 8 for various thicknesses of the seal layer and average fluid head conditions.

Laboratory permeability tests were made using a constant head permeater with 4-inch diameter and one inch thick clay samples using pond liquor as the permeating fluid. Clay samples were derived from a mine stockpile and the nearby dry lake.

Pond service lives calculated based on the above method are as follows:

Pond	Design Service Life (years)
A-E	20
4	30
5	15.8
6	16

(permeability = .002 ft/yr, porosity = 0.45)

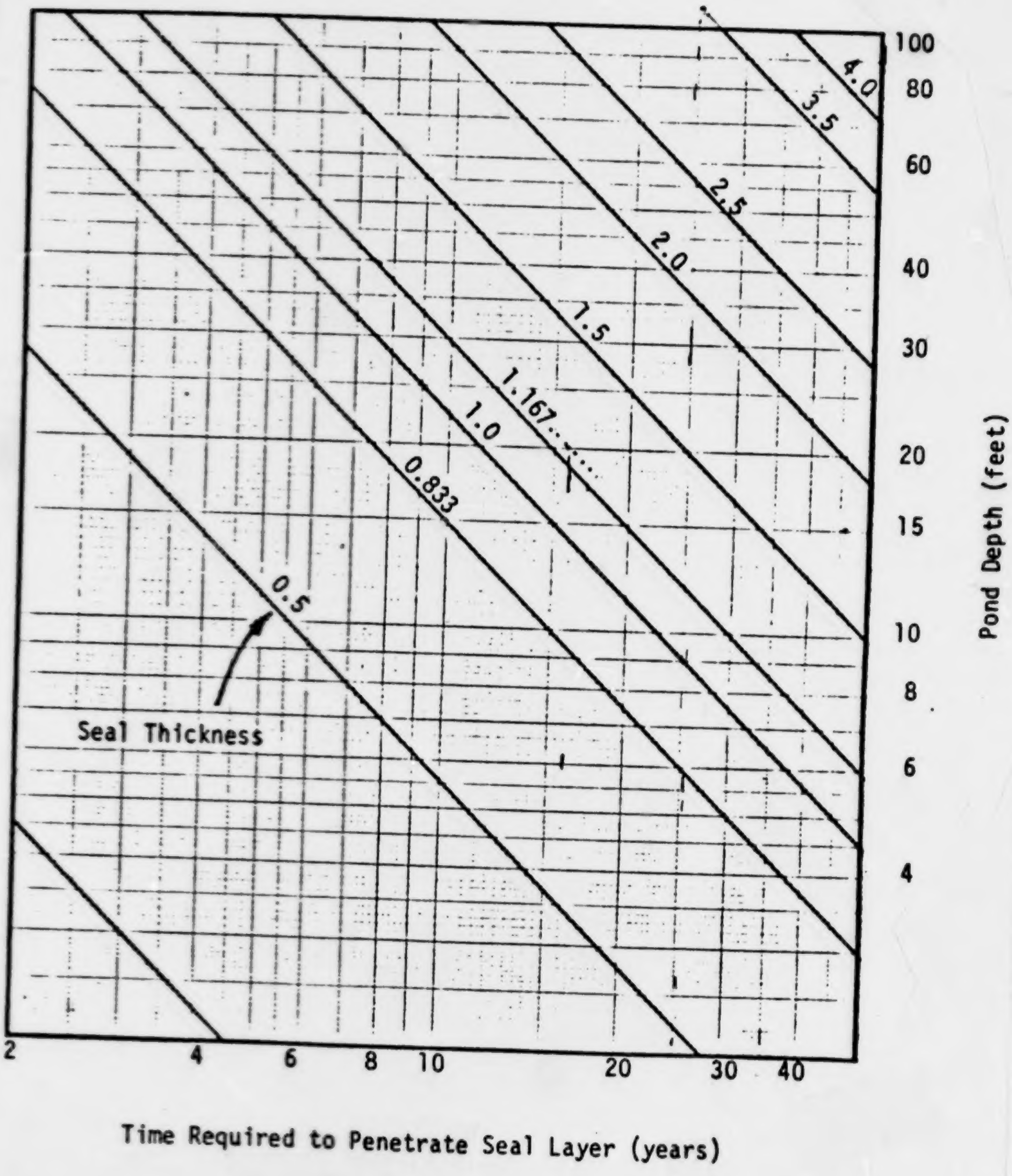

Figure 8. Parameters Affecting Pond Life

4.4 Site Hydrogeology

The facility is located in a sparsely vegetated desert region with local relief of about 15 feet. Alluvial deposits in the vicinity consist of semiconsolidated gravel, sand, silt, and clay. Several major faults are within 50 miles of the site. The potential exists for small magnitude events to occur on two faults situated eight miles northeast of the site.

Typical clay from the open pit mine contains a high proportion of montmorillonite clay, with about 5 percent extraneous impurities. The dry lake clay was originally mined for sale as a rotary drilling medium, and consequently has a very uniform consistency and engineering properties. Surface runoff in the area is primarily by sheet flow from small hills north of plant site, and generally occurs during periods of heavy rainfall. The ponds overlie clean sands and gravel which contains small amounts of groundwater. The major groundwater basin containing usable water is downgradient and southwest of the ponds.

4.5 Waste-Liner Compatibility

The owner/operator was concerned with the effects of wastewaters on clay permeability (see Section 4.3). Samples of clay from the mine and from a nearby dry lake bed were tested for permeability using the corresponding wastewater to be placed in each pond. For Pond 6, the effects of effluents typical with high sodium sulfate concentrations (approximating the waste liquor from the mineral acid plant) on clay permeability were evaluated for both mine clay and the dry lake bed clay.

4.6 Soil Permeability

No permeability data on the native soil beneath the ponds were available.

4.7 Regulatory and Permit Requirements

Wastewater discharge requirements were first established for this site in 1960 by the state. The requirements were subsequently revised seven times during the following twenty years. To protect the state's waters from potential contamination, the state currently requires the following:

- The average daily flow of wastewater from the mineral milling and processing operation to the tailings ponds during any 30-day period shall not exceed 3.0 mgd (131.4 l/s). The average daily flow of wastewater from the acid facility to Pond 6 during any 30-day period shall not exceed 0.566 mgd (25 l/s).
- The designated disposal sites for all industrial wastewater discharges shall be effectively sealed to prevent percolation of wastes.*

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*Effectively sealed shall mean a liner having a permeability of 1×10^{-8} centimeters/second or less and of sufficient thickness to prevent the migrtion of wastewater to underlying groundwater during the life of the facility.

- The discharge of wastewater except to the designated disposal sites is prohibited.

- Once the presence of wastewater is detected in any pond underdrain system (see Section 5.4), the continued discharge of wastewater to the subject pond is prohibited.

- There shall be no discharge, bypass or diversion of raw or partially treated industrial wastewater from the collection, transport, or disposal facilities to adjacent land areas.

- There shall be no surface flow or visible discharge of wastewater from the designated disposal sites to adjacent land areas.

- All facilities used for collection, transport, or disposal of waste shall be adequately protected against damage resulting from overflow, washout or inundation from a storm or flood having a recurrence interval of once in 100 years.

- The vertical distance between the water surface elevation and the lowest point of a pond dike or the invert of an overflow structure shall not be less than 1.5 feet (0.46 m).

The owner is also required to monitor the total volume of wastewaters and the total quantity and concentration of arsenic and boron in each pond. Leak detection sumps must be inspected monthly; ground water samples from 23 monitoring wells (see Section 5.5) must be analyzed to determine the concentration of total filterable residue, arsenic, and boron.

4.8 Cost Considerations

At one time, FMLs were considered by the site owner, but because the owner has access to large amounts of high quality, waste compatible clay on site, the owner felt that the use of FMLs would not be cost-effective. (There would be no mineral ore to mine and process if not for the presence of in-situ clay deposits which over geologic time has held the ore in place.)

5.0 DESCRIPTION OF DESIGN AND DESIGN SPECIFICATIONS

The design specifications for all clay-lined impoundments at this site are very similar. The only notable difference in impoundment design is for Pond 6. The embankments of this pond were lined with clay from an offsite source (a nearby dry lake bed) instead of clay from the mine. The construction specifications for Pond 6 are provided in Appendix B.

5.1 Dimensions and Configurations

The shallow evaporation ponds A through E have a nominal total surface area of approximately 75 acres. Pond 4 is a high-head circular impoundment, 80 acres in size and 20 feet deep. Pond 5 is a 100 acre, 40 foot deep, evaporation pond constructed in 1976 and modified (the embankments were raised from 20 to 40 feet) in 1979. Pond 6 has a nominal surface area of 120 acres and a maximum fluid depth of 20 feet. The embankments of Pond 6 will be raised sometime in the future.

5.2 Foundation Preparation and Embankments

The foundation and embankment construction procedures for each pond are outlined in Table 25. (For detailed information, see construction specifications, Appendix B.) A typical embankment drawing is shown in Figure 9.

5.3 Liner

Clay obtained from mine workings or a nearby dry lake stockpile (for Pond 6 embankments) was hauled to the pond area, spread in thin lifts, and processed extensively to obtain the desired moisture conditions prior to compaction. A 2 to 4 inch thick layer of gangue, designated as the "sacrificial" layer, was first placed over the subgrade to provide a working surface for construction equipment so that the foundation soil (i.e., sand) would not mix with the clay during clay liner placement/curing operations. The clay liner was placed in two layers approximately 8 inches in thickness each which are referred to as the seal layers after compaction.

The clay liner of each pond is designed to assure 100 percent containment of impounded liquid for a specified period of time. Therefore, for a given liner material, liner thickness depends on the design life of the pond and the design liquid head.

PONDS A-E

Basic clay soil processing for these ponds consisted of machine removal of all oversize particles (>4 inches) blading and spreading of each lift to a uniform surface, and watering to at least 115 percent of optimum moisture content.

A minimum compaction of 95 percent of maximum density was accomplished using a sheepsfoot roller with some pneumatic wheel rolling. The average thickness of the clay liner is slightly more than one foot, and only in a very few isolated instances, a total thickness of nine inches was noted during inspection.

POND 4

Compaction of the clay liner to at least 95 percent of maximum density was accomplished using sheepsfoot type compactors, track rolling, and pneumatic wheel rolling. The average thickness of the clay liner is

TABLE 25. FOUNDATION AND EMBANKMENT CONSTRUCTION PROCEDURES

Construction Step	Pond A-E	Pond 4	Pond 5	Pond 6
Site Clearing	Removal of vegetation, large rock and other unsuitable materials	Removal of vegetation, large rock and other unsuitable materials	Removal of vegetation, large rock and other unsuitable materials	Removal of vegetation, large rock and other unsuitable materials
Embankment Base				
Excavation	Surface soils were processed to a depth of about 12 inches.	Surface soils removed to a depth of 2 feet below existing grade	Surface soils removed to a depth of 1.5 feet below existing grae	Surface soils removed to a depth of 1.5 feet to 4.5 feet below existing grade
Compaction	Compacted to 90% of Proctor	Watered and brought to grade with compacted fill. (min compaction of 90%)	Watered well and compacted to a depth of 0.5 feet, brought to grade with compacted fill (min compaction of 90%)	Scarified, watered and compacted to at least 0.5 feet (min compaction of 90%)
Embankment	Fill from pond basin watered and compacted. Interior dikes constructed of course grained waste material from mines.	Fill from pond basin watered to 2% below to 3% above optimum moisture and compacted to at least 90% of Proctor. Interior slopes: proof-rolled parallel to embankment.	Fill from pond basin watered to 2% below to 3% above optimum moisture and compacted to at least 90% of Proctor. Interior slopes: proof-rolled parallel to embankment.-	Fill from pond basin spread in thin lifts, watered to optimum moisture, and compacted to at least 90% of Proctor. Interior slopes smoothed and proof-rolled parallel to embankment.

(Continued)

TABLE 25. FOUNDATION AND EMBANKMENT CONSTRUCTION PROCEDURES (Continued)

Construction Step	Pond A-E	Pond 4	Pond 5	Pond 6
Materials	No data	Approved granular alluvial soils and rock up to 8 to 12 in. not exceeding 10% of the total volume.	Approved granular alluvial soils and rock 4 to 6 in. not exceeding 10% of the total volume.	Approved granular alluvial soils and rock up to 2 to 4 in. not exceeding 20% of the total volume.
Final Slopes	All dikes are 1.5:1 (horizontal to vertical)	Exterior 2:1; interior 4:1 (horizontal to vertical)	Exterior 2:1; interior 4:1 (horizontal to vertical)	Exterior 2:1; interior 4:1 (horizontal to vertical)
Liner Thickness	Slightly >1 ft with isolated spots of 9 in.	2 ft average	2 ft average	1.1 ft
Protective Layers	Sand	6 inches of sand on pond base, 4 ft on embankment slopes; 8 to 10 inches of rip rap	6 inches of sand on pond base, 4 ft on embankment slopes; 8 to 10 inches of rip rap	6 inches of sand on pond base, 4 ft on embankment slopes; 8 to 10 inches of rip rap

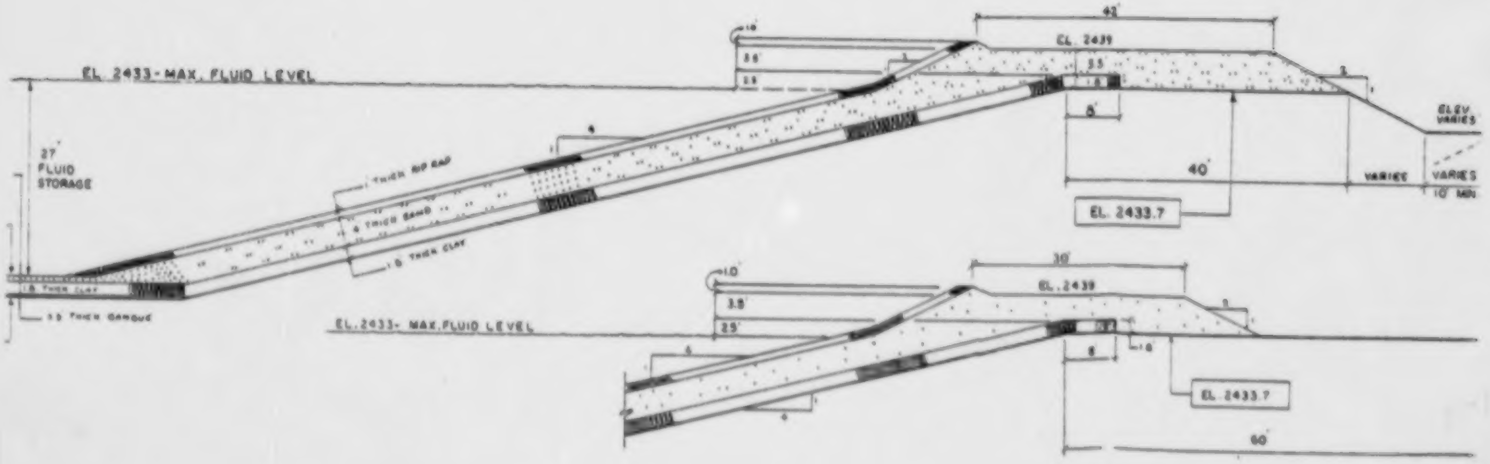
EL. 2433-MAX. FLUID LEVEL
27' FLUID STORAGE
1.0' THICK CLAY
3.0' THICK GRAVEL
1' THICK RIP RAP
6" THICK SAND
1.5' THICK CLAY
1.0'
3.5'
2.5'
42'
EL. 2439
3.5'
1.5'
8'
40'
EL. 2433.7
ELEV VARIES
VARIES
VARIES
10' MIN
1.0'
3.5'
2.5'
EL. 2433- MAX. FLUID LEVEL
30'
EL. 2439
1.5'
8'
EL. 2433.7
60'
1
2
1
4
1
6

Figure 9. Typical Embankment Design

slightly more than 1.5 feet; however, in a very few isolated instances, a total thickness of 2.0 to 2.5 feet was noted.

POND 5

The clay soils were processed with self-propelled mixing machines to obtain the desired moisture conditions prior to compaction. Soil processing and compaction was performed in stages. After the clay was placed in the pond bottom it was saturated and initially raked to remove large rocks. Water to about 130 percent of optimum was mixed into the clay with self-propelled machines, which generally required two passes to achieve uniform coverage. The moistened clay was then left to "cure" for a minimum period of 6 days with only occasional maintenance watering. Compaction of at least 95 percent of maximum density was obtained by several passes with a segmented-foot compactor followed by pneumatic wheel rolling.

The average liner thickness is slightly more than 1.5 feet. A thicker section of clay (2.0 to 2.5 feet) was placed at the west end to compensate for the greater head at this end of the pond.

POND 6

The pond bottom was first covered with a sacrificial layer of gangue material 0.3-feet thick, and 1.2 feet of processed clay were then placed. Material for the clay bottom was obtained from a designated mine stockpile.

The mine clay was screened to minus 4-inch to remove oversized particles at the stockpile. Sized clay was transported to the pond, spread in windrows, and thoroughly moisture conditioned with self-propelled mixing equipment.

Basic processing consisted of watering and blending to a uniform moisture content of about 125 percent of optimum. The processed material was then stockpiled and allowed to cure for at least 20 days. After curing, the clay was spread in lifts and compacted to at least 95 percent of maximum density. Moisture content was maintained by watering to at least 110 percent of optimum at the time of compaction.

5.4 Leak Detection

Except for Ponds A-E, all pond liners are underlain by a leak detection system (see Figure 10 for design). Independent monitor subdrains were constructed beneath each pond bottom, with a positive discharge gradient of 0.3 percent to the outlet. (Ponds 5 and 6 have two independent subdrains, while Pond 4 has three independent subdrains). The purpose of these subdrains is to intercept a random sample of any seepage through the pond bottom and carry it to one of the outlet stations.

Each subdrain v-ditch was excavated and lined with a continuous 10-mil polyethylene plastic sheet eight feet wide. Approximately 3 cubic feet of

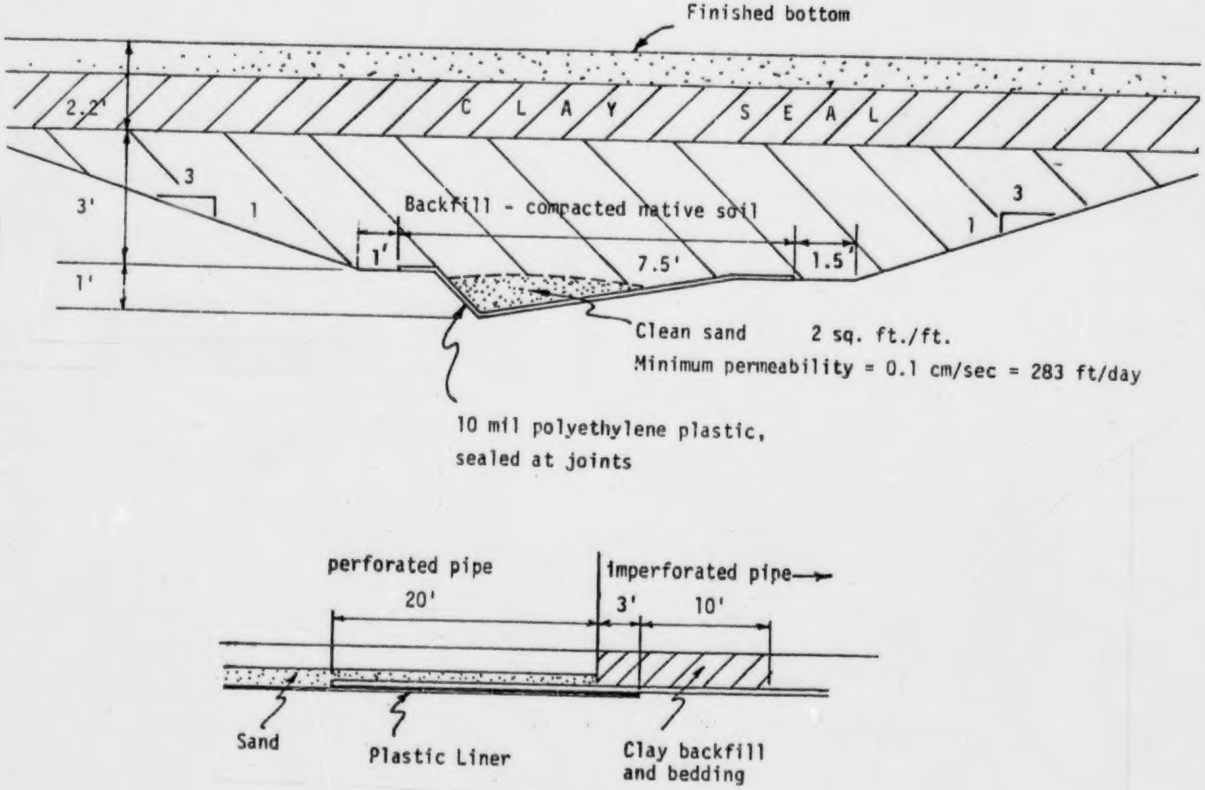
Finished bottom
2.2'
C L A Y S E A L
3
1
3'
Backfill - compacted native soil
1'
7.5'
1.5'
3
1
1'
Clean sand 2 sq. ft./ft.
Minimum permeability = 0.1 cm/sec = 283 ft/day
10 mil polyethylene plastic,
sealed at joints
perforated pipe
imperforated pipe
20'
3'
10'
Sand
Plastic Liner
Clay backfill
and bedding

Figure 10. Leak Detection System

select filter gravel (with minimum permeability of 0.04 cm/sec) was placed on the plastic sheet per foot of length to provide a permeable fluid collector and conduit. The resultant subdrain section was then covered with on-site, compacted, sandy soil. The outlet structure of each drain consists of a 3-inch perforated plastic pipe (having a minimum crush strength of 1250 lb/ft) embedded in the gravel of the interior toe of the pond embankment connecting with a 3-inch non-perforated plastic pipe extending under the embankment to a 4-foot diameter observation sump.

Each leak detection system covers at least 2 percent of the impoundment bottom. Seepage is not expected to show up in any system during the expected life of the pond. If it does, indicating failure of the liner, the pond will be drained and placed out of service.

Other monitoring systems, such as shallow and deep perimeter wells and wells which are slant drilled under the impoundment have been studied by the geotechnical consultant. These systems were not recommended, because they would "inadequately detect the limited volume of fluid which could reasonably be anticipated." More importantly, the inadequate performance of the pond liner would be detected much too late for proper action. The placement of thermistors under the pond liners to register an increase in moisture content of the soil was also considered, but rejected as it was felt that the system suffers "the disadvantages of limited coverage for practical installation and unreliable results in comparison with direct observation."

5.5 Ground Water Monitoring

Samples from twelve ground water monitoring wells and eleven interceptor wells are analyzed quarterly for TDS, arsenic, and boron content. The 12 ground water wells are located south (downgradient) of the clay lined and unlined (abandoned) ponds. These wells were drilled in 1975 and first sampled in 1976, approximately one year after the unlined ponds were abandoned. The interceptor wells were drilled in 1977 as part of a proposed method of intercepting leakage from the 3 abandoned tailings ponds. Currently, about 2 million gallons per month are pumped from the interceptor wells.

5.6 QA/QC Specifications

Specific requirements for QA/QC in connection with the installation of clay liners and general construction of each pond are detailed in the construction specifications attached to this case study report. Waste-liner permeability test results are documented in the feasibility study prepared by the geotechnical consultant for each pond. The state agencies involved in issuing a wastewater discharge permit (water quality board) and certificate of approval for small earthfill dams (department of safety of dams), the geotechnical consultant, as well as the site owner, were closerly involved in the design, construction, and installation of each clay lined pond.

The geotechnical consultant prepared a "Report of Compacted Fill" which presented the results of their field inspections and tests performed during construction of each pond. As requested by the site owner, the geotechnical consultant inspected and tested the following: 1) preparation of the embankment foundation; 2) installation of the subdrain monitoring system; 3) placement and compaction of the embankment fills; 4) processing, placement, and compaction of the clay seal liners; 5) placement of protective sand and rip-rap blankets; and 6) construction of associated inlet/outlet structures and provisions. The test methods and inspection procedures used by the geotechnical consultant are as follows.

The maximum dry density and optimum moisture content of the representative soils used within each pond were determined in both the field and laboratory by ASTM Test Method D 1557-70 for the embankment material and ASTM Test Method D 698-70 for the clay seal layer. Compaction curves were drawn up based on the results of these tests.

The fill placement operations were under continuous inspection and testing by qualified soils technicians. When a test indicated compaction below the required density, the subject area was removed or reworked, recompacted, and checked by additional testing. Relative compaction tests were made by the drive cylinder method (ASTM D 2937-71), and the sand volume method (ASTM D 1556). All test locations were recorded on a map. During the progress of each job, the results of the compaction tests were periodically submitted to the site owner and reviewing governmental agencies.

Undisturbed samples of the compacted clay liners of each pond were hermetically sealed in wax for transportation to the laboratory. The samples were trimmed to four-inch diameters with a thickness of two inches and tested by a constant head permeater. The tests used de-aired pond liquor as the permeating fluid.

Grading analysis were made on representative samples of rip-rap taken from quarry stockpiles and the in-place blanket. A durability index test was also made on samples of rip-rap.

QA/QC results are summarized below for each pond:

PONDS A-E

A total of 355 relative compaction tests were taken on the site during fill placement operations to control compaction density. Fifteen in-place permeability samples were obtained periodically during construction. The last 3 samples were taken in the dikes in the direction of flow and this resulted in higher rates of flow. A mean horizontal flow of 0.4×10^{-8} cm/sec can be anticipated. Based on results of the 12 permeability tests using pond liquor, a range of 0.2×10^{-9} cm/sec to 2.4×10^{-9} cm/sec was found with a mean value of 1.6×10^{-9} cm/sec. One sample was eliminated, because it was believed that some channeling adjacent to a shale fragment or along the sample edge occurred. Even using this sample, the mean value is within the design permeability of 2×10^{-9} cm/sec.

Based on inspections and the results of all tests obtained at the site, it was concluded that the grading had been done in accordance with recommendations and with good engineering practice. It was further concluded that the clay shales placed at the bottom of pond areas had been properly placed and compacted with the desired moisture content. The results of the permeability tests indicated that materials had the desired impermeability and the design pond life would be obtained.

POND 4

A total of 1,376 relative compaction tests were taken during fill placement operations to control compaction density. Twenty-six in-place permeability samples were obtained periodically during grading at this site. Based on twenty-three samples, the permeability ranged from 0.6 x 10^{-9} cm/sec to 3.67 x 10^{-9} cm/sec with a mean value of 1.74 x 10^{-9} cm/sec.

Based on the inspections and the results of all tests obtained at the site, it was concluded that the grading was done substantially in accordance with the contract plans. The results of the permeability tests indicated that the seal was suitable, and the desired life of the pond would be obtained. The overflow pipe was encased in concrete. The inlet tailing line was not encased in concrete since it probably will be moved to avoid a large buildup of tailings.

POND 5

A total of 1,810 relative compaction tests were taken during fill placement operations to control compacted density of the soil.

Forty-six (46) permeability samples were obtained from the compacted seal layer during grading at the subject site. Due to a change in the source of the clay shale toward the end of the construction, some of the permeability tests exceeded the maximum value of 2 x 10^{-9} cm/sec. To compensate for this condition, two to four inches of additional clay seal thickness were placed in these areas to provide an equivalent pond life.

Based on observations and the results of all the tests obtained at the site, it was concluded that the grading was done substantially in accordance with contract plans and specifications.

Using the criterion of zero leakage, the life of the pond is equal to the time required for the pond fluid to pass completely through the seal layer. For the typical case where the seal consists of sixteen inches of seal over two inches of sacrificial clay, and has a maximum permeability of 2 x 10^{-9} cm/sec., the pond life is 15.8 years under the full head of 20.8 feet, the seal thickness was increased sufficiently so that the pond life in these areas would be at least as great as it is in the typical case. If the pond level is maintained below the maximum elevation for a portion of the storage life, it will increase the pond life beyond the minimum period of 15.8 years.

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POND 6

A total of 2,047 relative compaction tests were taken during fill placement operations to control compacted density of the soil.

A total of 70 undisturbed samples were obtained from the compacted clay seal liners during construction. Tests on the compacted clay liners determined that all the samples had permeabilities less than the design criteria of 2×10^{-9} cm/sec. Average transmission rates of 0.5×10^{-9} cm/sec for the bottom seal and 1.5×10^{-9} cm/sec for the embankment seals were measured.

Based on observations and test data obtained from both field and laboratory work, it was concluded that the finished earthwork was constructed substantially as required by the contract plans and specifications. During the course of construction all the required inspections and approvals by various agencies having jurisdiction on this project were completed.

Pond 6 was designed and constructed to provide effluent containment with zero leakage. Pond life is equal to the time required for the pond liquor to penetrate the seal layer, and is a function of the seal thickness, permeability and the hydraulic head. The design thickness and permeability criteria were accomplished and, assuming the pond is filled according to schedule, the facility will have the planned storage life. Permanent bench marks placed on the completed embankment are to be surveyed regularly to measure embankment settlement during the life of the pond.

All compacted fill reports were prepared in accordance with generally accepted geotechnical practices and make no other warranties, either expressed or implied, as to the professional advise or information presented. The reports are based on the project as described and the data obtained from field or laboratory tests and observations. A re-evaluation of the conclusions and recommendations made by the consultant may be required if any "pertinent" changes in site conditions differing from those described in the

6.0 DEVIATIONS FROM DESIGN, PROBLEMS ENCOUNTERED DURING CONSTRUCTION, AND COSTS

No data are available on the cost of constructing any of the clay-lined ponds. No deviations/modifications to the original plans of Ponds A-E, 4, 5, or 6 were noted. The only major problem encountered during construction was maintaining the proper moisture content. (If the clay becomes too wet, the construction equipment can't operate properly on the lift; the clay soil is barely plastic, and creep deformation can occur. If the clay is too dry, the proper compaction is not achieved.) Water to about 130 percent of optimum was mixed into the clay with self-propelled mixing machines and left to cure for several days. After, curing, the clay was again mixed and water added to maintain at least 110 percent of optimum moisture. Where field tests indicated the compacted clay did not meet the specified moisture content or

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adequate relative compaction, the unapproved area was reconditioned and/or recompacted.

The site owner and geotechnical consultant were aware of desiccation cracking problems associated with clay liner installation in dry climates. Besides clay curing and compacting wet of optimum, the pond liners were constructed in sections (from lowest to highest grade) and immediately backfilled or filled with wastewater to eliminate desiccation cracking.

During processing of the clay in the bottom of Pond 5, problems from rock damage to the mixing equipment was noted. Apparently, initial raking of clay placed in the pond bottom to remove excessive and/or large rock proved inadequate. The clay was subsequently screened to remove rock prior to placement on the pond bottom.

7.0 PERFORMANCE DATA AND OPERATING EXPERIENCE

Data generated during ground water and interceptor well monitoring activities for abandoned Ponds 1-3, reveal that given the opportunity (e.g., unlined ponds), a significant volume of wastewater can migrate rapidly through the subsoils away from the site (see Table 26). These ground water monitoring wells can't however, be used to assess the performance of any individual clay-lined pond, because all of the monitoring wells are located downgradient (southwest) of all clay-lined and unlined (abandoned) ponds.

Leak detection subdrains used to monitor the ability of the clay liners to contain impounded wastewaters were constructed under Ponds 4, 5, and 6. (Ponds A-E were designed and constructed before leak detection systems became a widely used technology.) Based on inspection reports of these leak detection subdrains, the clay liners beneath Ponds 4, 5, and 6 are performing well. (The subdrains are monitored monthly by the site owner and at least quarterly by the state.) The good performance of the clay liners is very much expected since the clay used to line the Ponds has held the mineral ore deposits mined at this facility for centuries.

The ability of the subdrain monitoring systems to detect seepage was first questioned by the state in November 1979. State representatives suggested that the subdrain monitoring systems "provide a false sense of security, because of limitations in the design." Because of the low gradients of the subdrains (0.3 percent) and the possibility of differential settlement of the foundation beneath the subdrains, the state was concerned that: 1) drainage would be disrupted under loads of 20 to 40 feet of solids and water; and 2) it may take hundreds of years to detect leakage. Furthermore, state personnel inspecting the construction of Pond 6 observed large earth scrappers driving over the rock-filled polyethylene v-ditches before any backfill was placed. They also questioned the permeability of the gravel/sand mixture which was being placed over the plastic sheet.

Because of the State's concerns, it was decided that construction of a test section of subdrain at the Pond 6 site would be the best way to determine whether the subdrain system actually works. The results of this test were reported by the state as follows:

TABLE 26. ARSENIC CONCENTRATION RANGES IN WELL 11/8-22LI (mg/l)

Year	High Value	Low Value
1970	0.23	0.01
1971	0.04	0.02
1972	0.05	0.04
1973	0.05	0.02
1974	0.07	0.02
1975	4.10	0.07
1976	21.8	7.70
1977	15.9	17.9
1978	29.6	14.7
1979	25.2	17.5
1980	32.9	20.1
1981	26.1	19.3

"This is to document the results of the in-place test of the subdrain leakage detection system in Pond 6 on June 6, 1980. During the test State representatives observed that a test section was constructed in a manner closely resembling isolated field conditions. A section approximately 18-1/2 feet long was then isolated and water was applied at the upgradient end to simulate leakage through the clay liner in the event of failure. Water was detected at the downgradient end of the test section approximately six minutes after initiation of the test, making the test highly successful in our view."

"The above-described results verify that the materials placed within the subdrain and the grades used in the subdrain are adequate to convey water such as would result from a failure of the clay liner in the pond. It is very important and encouraging that the subdrain functioned as it did so that the state may have confidence in both the design and construction of the systems. This will allow a greater understanding of the operation of such leakage detection systems and will facilitate reviews of future submittals by the owner..."

All ponds receive wastewaters via overhead floating (plastic) pipes. The owner performs depth soundings from a boat twice a year to ensure that the flow of solids is distributed evenly throughout the ponds. Splash pads were initially placed in all ponds at the start of pond operation.

PONDS A-E

After ten years of service, approximately 1-1/2 feet of solids had accumulated on the bottom of the ponds. A mineral harvesting experiment was conducted in one of these low-head evaporation ponds. This provided an opportunity to also sample the pond's clay liner. Six core samples of the clay liner (10 to 12 inches thick) were taken and analyzed by the company's research laboratory. The core holes were subsequently recompacted with clay soil. The purpose of the experiment was to pinpoint by chemical analysis the depth into which the waste liquor had penetrated the liner in order to establish the pond's current service life.

The results of the study were inconclusive. No interface between the waste liquor and clay liner could be identified by the methods used.

PONDS 4 AND 5

These high-head ponds are performing well after six to seven years of service. Based on leak detection system inspection reports, the 18-inch clay liners continue to hold the impounded tailings slurry.

It was first noted that Pond 4 was filling with solids much more quickly than expected only a few months after the pond was built. In 1978, Pond 4 was nearly full of solids and it was projected that despite the construction of Pond 5, additional liquid storage volume would be required before May 1980. The owner requested that the state consider allowing them to raise the dikes on Pond 5 from 20 to 40 feet. The request was granted and Pond 5 was enlarged, following the same design criteria, inspection, and testing procedures used in the original construction.

The average conditions for Pond 5 consists of the bottom clay liner 16 inches thick placed over 2 inches of similar sacrificial clay which have a maximum permeability of about 2×10^{-9} cm/sec. Under conditions of the maximum hydraulic head provided by raising the embankment, the new minimum pond life is ten years.

POND 6

Based on leak detection monitoring reports, Pond 6 has been performing well for over two years. The company has, however, encountered an unusual and certainly unexpected problem with the clay liner on the embankments of Pond 6.

As previously noted, only the embankments of Pond 6 are lined with clay from an off-site source (dry lake) instead of clay from the mine. Because the acid plant effluent has slightly different characteristics than the tailings slurry from the refinery, and because the mine clay contains some mineral ore, the company was concerned about possible chemical reactions between the effluent and the mineral ore in the clay where an air interface is present (i.e., on slopes). So the company decided to use the dry lake clay, since tests showed that no reaction of this kind would occur with this clay.

What the owner and consultant had not anticipated was the possibility for development of sinkholes due to the action of rainwater on the highly dispersive dry lake clay. Thus, after a heavy rainfall, the interior embankment slopes experienced sinkholes due to deflocculation and suspension of clay particles in the fluid medium. Two investigations were conducted by the geotechnical consultant after the sinkholes were first noted. The results of these studies are described below.

The initial investigation of sinkholes on the Pond 6 embankment consisted of inspecting the embankment and excavating four backhoe trenches adjacent to some sinkholes. The trenches revealed open underground water conduits traced from the sinks toward the rip-rap covered portion of the embankment. In two cases, the loss of equal portions of clay and overlying sand resulted in the observed conduits. In the second study, portions of the embankment clay seal layer were examined. Areas of the clay liner with evidence of piping were found where the clay had substantially less than 2 feet of sand cover. Most piping conduits tended to decrease in size with depth. Sandy material near the conduits was filled with clay apparently originating from dispersion of the clay seal.

A specific chain of circumstances produced the conditions that promoted dispersion. Pond water saturated the lower portion of the protective slope blanket. Rain runoff from the embankment crest washed sand onto the bench and clogged the rip-rap. Later, rain water ponded on the embankment bench where it infiltrated downward until it encountered the clay seal, then flowed down slope on top of the seal. Because of the dispersive nature of the dry lake clay as opposed to the mine clay, the clay was literally eroded by the percolating rain water, was carried in suspension through the pores of the sand blanket, and was either deposited at lower points along the flow path or transported into the pond liquor. (See Figure 11.)

The following corrective actions were undertaken. Existing sink holes were filled with gangue. Rain water ponding was eliminated by grading to promote discharge via drain pipe. Repairs were completed in July 1982. Since that time, no sink holes have been observed in Pond 6.

DATA SOURCES USED

1. State Waste Discharge Requirements, 1980.
2. Tailings Pond Ground Water Monitoring Report, February 1976.

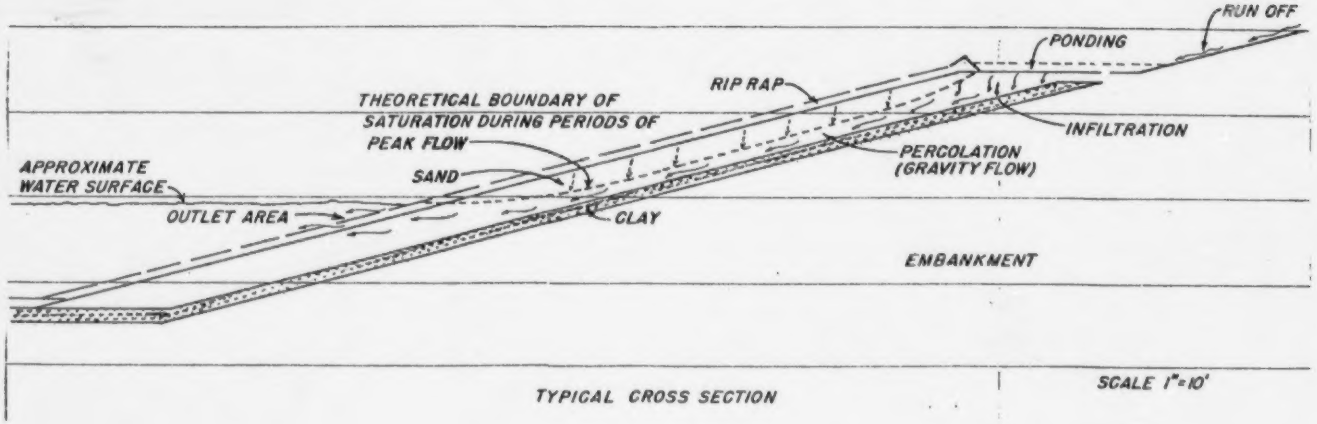

RUN OFF
PONDING
RIP RAP
INFILTRATION
THEORETICAL BOUNDARY OF SATURATION DURING PERIODS OF PEAK FLOW
PERCOLATION (GRAVITY FLOW)
APPROXIMATE WATER SURFACE
SAND
OUTLET AREA
CLAY
EMBANKMENT
TYPICAL CROSS SECTION
SCALE 1"=10'

Figure 11. Hydrologic Regimen for Pond 6 Sinkhole Phenomenon

3. Self-monitoring Reports, 1970 through 1982.
4. Feasibility Study For Ponds A-E, August 1971.
5. Report of Compacted Fill For Ponds A-E, November 1973.
6. Construction Specifications For Pond 4, September 1974.
7. Report of Compacted Fill For Pond 4, February 1976.
8. Construction Specifications For Pond 5, November 1975.
9. Report of Compacted Fill For Pond 5, April 1977.
10. Report of Compacted Fill For Pond 5, April 1977.
11. Report of Compacted Fill For Raised Pond 5, June 180.
12. Feasibility Study For Pond 6, August 1979.
13. Construction Specifications For Pond 6, December 1979.
14. Report of Compacted Fill For Pond 6, June 1981.
15. Draft Environmental Impact Report for Proposed Boric Acid Plant Discharge Pond, September 1979.
16. Investigations of Sinkhole Phenomena, Tailings Pond 6, 1982.
17. Various State Inspection Reports/Correspondence.
18. Data Provided by Facility Owner During Site Visit on 23 June 1983.

CASE STUDY NO. 6

1.0 GENERAL DESCRIPTION AND HISTORICAL BACKGROUND

The surface impoundments discussed in this case study are part of a privately owned and operated commercial hazardous waste disposal facility. These surface impoundments were designed and constructed primarily for the treatment and ultimate disposal of liquid wastes from the geothermal industry (1). Other wastes also accepted at the site include those from agriculture, storm water runoff from areas handling hazardous wastes, cooling tower and boiler operations, gas and oil exploration and production and wastewater treatment plus small amounts of other miscellaneous hazardous wastes. Treatment of the wastes in the surface impoundments is via solar evaporation or biodegradation. Ultimate pond closure will involve covering the dewatered material with three feet of clay soil at a drainage slope of 3 to 5 percent and revegetation with native plants.

The waste disposal site is being developed in five phases with an eventual total capacity of almost 8 million barrels and an expected service life of 30 to 50 years. The first phase of development, which began in late 1980, is to consist of ten disposal areas or cells on approximately 50 to 60 acres. Of the seven ponds presently certified for liquid disposal, only three ponds have a substantial operational record. These ponds are labeled ponds 3, 5 and 8 in Figure 12. Each five-acre pond is capable of receiving approximately 230,000 barrels (42 gallons per barrel) of liquid waste per year. This waste is expected to evaporate to a final volume of about 116,000 barrels. Total receiving capacity of the Phase I surface impondments is about 1,200,000 barrels or roughly 50 million gallons. The final volume after evaporation is estimated to be about 580,000 barrels or approximately 24 million gallons (1).

The waste facility is located in a desert area in the southwest, characterized by sparse vegetation and an average annual precipitation of only 2.15 inches. The site is situated on 640 acres (one square mile section) of which 300 to 400 acres are considered suitable for hazardous waste disposal. Prior to establishment of the waste facility the land was vacant, unirrigated desert. Adjacent land areas are also uncultivated desert. The closest public road to the site is one mile away. North of this road is irrigated cropland. The nearest dwelling is a farmhouse about one mile to the east (1).

2.0 BASIS FOR SITE SELECTION

Site selection was based upon the results of a geologic survey performed by the state. The state recommended areas especially suited to the construction of evaporation ponds and the operator purchased the only privately owned land within the recommended areas. Evaporation rates for the area are high, 72 to 84 inches per year. The site is also in close proximity to its primary user, the geothermal industry (4).

3.0 DESIGN, CONSTRUCTION AND INSTALLATION FIRMS UTILIZED

The facility was designed by the owner/operator but constructed by an outside construction firm. Site and construction investigations, including ground water monitoring, were provided by an outside third-party geotechnical engineering firm.

4.0 DESIGN CRITERIA

4.1 Purpose of the Surface Impoundments

The purpose of the surface impoundments at this site is storage and ultimate disposal via solar evaporation of geothermal and other wastes.

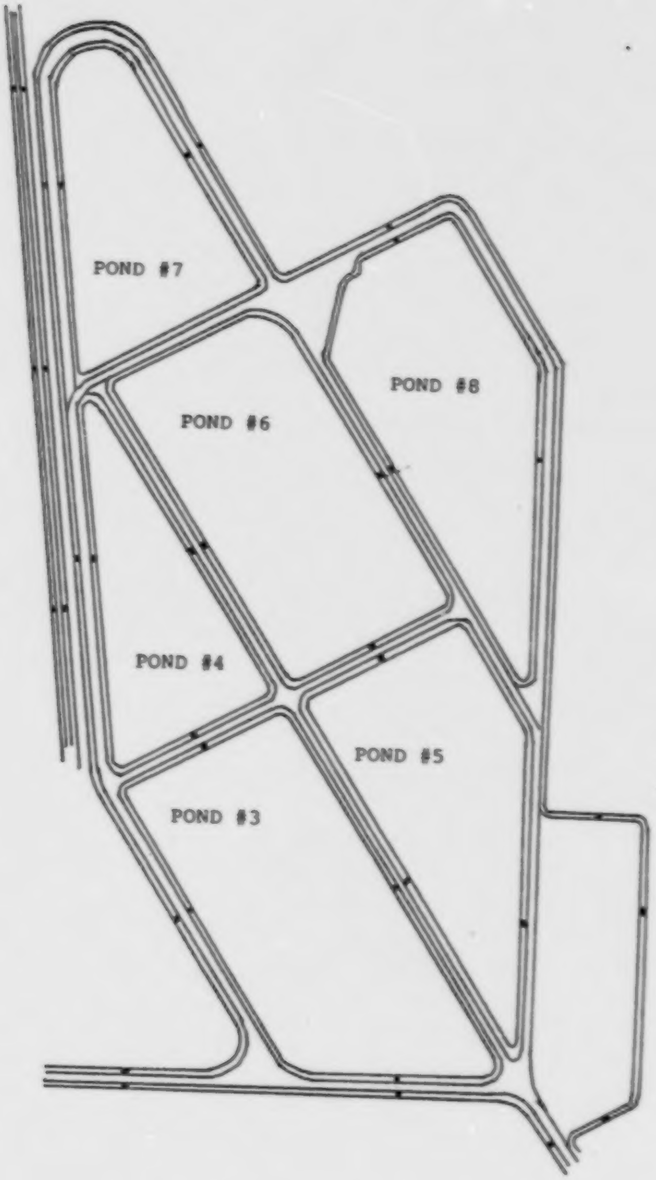

POND #7
POND #8
POND #6
POND #4
POND #5
POND #3

Figure 12. Layout of Phase I Surface Impoundments (3)

4.2 Waste Characteristics

Wastes received at this facility and disposed of in surface impoundments are primarily geothermal wastes but also include wastes from the petroleum industry, wastewater treatment sludges, cooling tower blowdown sludge, stormwater runoff from areas used to handle wastes and neutralized aqueous acidic or alkaline solutions (5). The wastes generated by the geothermal industry are mainly brines and muds from well drilling, well testing and power plant operation. The precise composition of the wastes varies with the source area and drilling technique; however, they are usually classified as hazardous wastes by the state and require disposal at a hazardous waste site.

Specific wastes from geothermal facilities include rotary drilling muds, work-over or clean-out fluid, well-testing fluid geothermal brines and residues. The operator expects to receive from 1000 to 3000 barrels per day of such materials (5). Thus far, actual receipts have been much less than this amount. The majority of the geothermal wastes received at this site are geothermal brines.

Typical constituents in a geothermal brine are listed in Table 27.

In 1981 only pond 8 was used as a surface impoundment. Ponds 3 and 5 were used for land farming operations. Approximately 13 million gallons of wastes were put into pond 8 in 1981 (6). A breakdown of the wastes received is in Table 28. An analysis of the waste in pond 8 in April of 1981 by the state is reported in Tables 29 and 30 (3).

4.3 Service Life

Each of the three present Phase I surface impoundments has an expected service life of four to six years. The entire five phase development is expected to be in operation 30 to 50 years (1,5).

4.4 Hydrogeological Studies

Geotechnical investigations were performed by a consulting engineering firm prior to, during and after construction of the surface impoundments. The initial investigation covered several aspects of site evaluation, the most important of which were the nature of the underlying materials, seismic activity and flooding (4).

The site is underlain with ancient lake beds of low permeability to a depth of at least 100 feet. Lake bed sediments have been shown to exist to a depth of 710 feet in the drilling of a water supply well.

Geologic investigations were made of seismic activity in the general area of the site and on-site. The closest off-site active fault was located four miles to the southwest. This fault is capable of generating moderate strength earthquakes. Other active and potentially active faults were found 8, 10, 12, 14, and 19 miles away. On-site three fault-like segments or branches termed fractures were identified.

TABLE 27. TYPICAL GEOTHERMAL BRINE COMPOSITION (1)

(in milligrams per liter (mg/l)
of total well fluid)

Component	Concentration
Total Dissolved Solids (TDS)	82,900
Cl^-	47,300
Na^+	20,100
K^+	4,060
Ca^{++}	5,530
Ba^{++}	363
Sr^{++}	344
Li^+	100
Mg^{++}	34
B	110
SiO_2	527
Mn^{++}	189
Fe^{++}	123
Zn^{++}	14
Pb^{++}	1.1
As^{+++}	2.6
Ag^+	0.2
Cu^+	0.11

TABLE 28. WASTES DISPOSED IN POND 8 IN 1981 (6)

Source of the Waste	Amount Received in Million Gallons	Percent of Total Waste in Pond 8
Geothermal Industry	7.4	56.9%
Petroleum Industry	4.0	30.7%
Wastewater Sludge	0.47	3.6%
Other	1.15	8.8%

TABLE 29. METAL ANALYSIS OF POND 8 WASTE IN mg/l (3)

Metal Constituent	Sediment	Liquid
Antimony	1.2	12
Arsenic	42	0.45
Beryllium	1.1	0.049
Cadmium	3.7	1.7
Chromium	24	0.27
Copper	98	1.0
Lead	660	19
Mercury	0.09	0.001
Nickel	11	1.9
Selenium	1.1	1.7
Silver	28	0.69
Thallium	8.3	3.1
Zinc	450	300
Vanadium	330	2.5
Manganese	1100	940

TABLE 30. CONSTITUENTS FOUND IN THREE SEPARATE SAMPLES OF WASTE FROM POND 8 IN ppb (3)

Chemical Constituent	Sediment and Liquid			Liquid		
	1	2	3	1	2	3
Benzene	280	1900	ND	ND	ND	ND
Chlorobenzene	150	ND	ND	ND	ND	ND
Ethyl Benzene	440	3500	ND	ND	ND	ND
Methylene Chloride	ND	ND	30	ND	200	ND
Tetrachloroethylene	70	ND	28	ND	ND	ND
1,1,2,2, Tetrachloroethane	72	ND	28	ND	ND	ND
Touluene	2200	4300	ND	ND	ND	ND
Trichlorofluoromethane	130	ND	ND	ND	ND	ND
1,1,1 Trichloroethane	280	1100	720	32	800	62
1,1 Dichloroethane	ND	ND	38	ND	46	ND
Anthracene/Phenanthrene	5100			ND		
Benzo(a)anthracene/Chrysens	830			ND		
Bis(2-ethyl hexyl) Phthalate*	12000			20		
Di-N-Octyl Phthalate	ND			4		
Butyl Benzyl Phthalate	130			ND		
Napthalene	4200			ND		
Pyrene	1500			ND		
Phenol	ND			900		
Cyanide	270			>20		

*The high concentrations of Bis-phthalate are believed to be contamination from the sample bottles and not representative of wastes contained in the ponds.

Analysis of historical earthquake data indicated a hypothetical maximum probable earthquake at the site of magnitude 7.2 with a return period of 100 years. During an earthquake the intensity of ground shaking is greatest within about a 12 mile radius of the fault and decreases with distance from the fault.

Hydrological investigation of the waste site focused on the effects of the occurrence of a hypothetical 100 year storm. Storm intensity was estimated to be a maximum of 1.5 inches/hour. Surface runoff to and from the site was found to have a northeasterly direction both as sheet flow and channel flow. There are natural channels and washes on-site averaging 10 to 15 feet wide and 2 to 4 feet deep. The largest of the channels, the main drainage channel, is 30 feet wide and 10 feet deep and runs diagonally through the site from the southwest to the northeast. Several natural gullies to the north drain into this channel.

Peak stormwater runoff was estimated to be 1000 cfs in the northeast, 700 cfs at the southwest and 1200 cfs on the southern and eastern boundaries of the site. Stormwater runoff from the site ultimately drains into an improved unlined drainage channel one-half mile northeast of the site. This drainage channel protects an adjacent freshwater canal from runoff inundation and erosion.

Groundwater elevation and quality beneath the site was determined in the preliminary geotechnical site investigations. Groundwater levels are from 30 feet below the surface on the western boundary to more than 90 feet below the surface on the western boundary. Flow is in an easterly to northeasterly direction. The geologic fractures identified on-site are not barriers to groundwater movement. Chemical analysis indicate that the water is saline and has a high TDS (total dissolved solids, 1300 to 2800 ppm). This water is not suitable for agricultural or domestic use. It exceeds the recommended public health standards for sulfate, chloride and TDS.

As a consequence of the poor groundwater quality, there were no wells found within 2-1/2 miles of the site. A 1976 USGS survey indicated that with no beneficial use of the groundwater, there were no wells within a 10 mile radius of the site. Water for domestic and agricultural use in the area is imported via canals.

4.5 Waste-Liner Compatibility

No waste-liner compatibility testing was required or performed. Natural in-situ clay was used as liner material.

4.6 Soil Permeability

Laboratory tests indicated permeabilities of 1.4×10^{-6} cm/sec to 1.2×10^{-8} cm/sec for the lake bed sediments. The higher values reflect the presence of sand deposits that need to be blanketed to achieve the 1×10^{-6} cm/sec permeability required by state regulations.

4.7 Regulatory and Permit Requirements

This hazardous waste disposal facility is regulated by EPA under RCRA. Such facilities are licensed locally by state and county government agencies. Application is made to the state for a waste discharge permit. An environmental impact report and operations plan are submitted to the county for approval. Some of the requirements of these government agencies were discussed in terms of soil permeability and pollutant attenuation. Other requirements, such as those for groundwater monitoring, are introduced in this section. The overall permit requirements for this site are listed in Table 31 (5).

Monitoring of the elevation and quality of groundwater was required within and around the site. Background information was to be obtained during the first year of sampling. After this initial period, certain analyses were to be made annually and semi-annually.

TABLE 31. BASIC GOVERNMENT REQUIREMENTS FOR ESTABLISHMENT OF CASE STUDY 6 HAZARDOUS WASTE SITE (5)

There shall be no discharge to surface drainage or groundwater and no overflow or seepage from the ponds.

The surface impoundments shall be inspected weekly for amount of freeboard (should be 2 feet), any seepage from the ponds and the general condition of the berms.

Pond bottoms are to consist of at least 2 feet of compacted/natural clay with a permeability of 1×10^{-6} cm/sec. Pond bottoms must not be less than 6 feet above the highest anticipated groundwater level.

Pond liner material must have a permeability less than or equal to 1×10^{-6} cm/sec.

Surface impoundments are to be protected from the 100 year flood.

Protection shall also be afforded against the maximum probable earthquake which appears to be reasonably expectable within a 100-year period.

Wells to monitor the elevation and quality of groundwater will be installed within and around the site. Groundwater samples are to be taken quarterly for 4 consecutive quarters and analyzed for various chemical parameters. After this initial testing period, certain tests will be run either annually or semi-annually.

An operations and closure plan with provision for long term maintenance must be filed with the state.

Upon termination of use, the pond must have a 3 foot thick cover, of which one foot must have a permeability $<10^{-6}$ cm/sec.

4.8 Cost Considerations

No information was available regarding cost considerations as design criteria.

5.0 DESCRIPTION OF DESIGN AND DESIGN SPECIFICATIONS

5.1 Recommendations Based on the Hydrogeological Study

It was the opinion of the geotechnical engineering firm that performed the initial hydrogeological investigation that establishment of a waste disposal facility at this site was "geotechnically feasible" (4). Provisions were made by this firm and the state that the facility be constructed with certain site improvements to protect against earthquakes, flooding and possible pond leakage (4,7). Setbacks of 100 feet from identified fault-like segments were recommended. Trenching was also deemed necessary to ensure that the fractures did not branch off beyond the setback areas. In addition, the levees on-site were required to be designed to withstand seismic shaking. Laboratory shear strength tests were recommended on remolded and undisturbed soil samples. These data could then be used in design of the levees.

Analysis of the drainage area upstream from the site and on-site indicated a need for improvement of an off-site upstream diversion channel and site perimeter storm channels. Only minor improvements were necessary on-site, especially to the main drainage channel that runs through the site. This main drainage channel was determined with minor improvements to be adequate to contain runoff from the 100 year storm. These minor improvements will allow this channel to handle a peak flow of 700 cfs at the southwest corner and 1000 cfs to the northeast.

An existing berm found west (upstream) of the site was designed to divert flow from the main on-site drainage channel and ultimately away from the downstream off-site storm drainage channel to the northeast. Diversion of storm flow of up to 5000 cfs at this point plus installation of drainage ditches to handle a storm flow of 1200 cfs on the southern and eastern boundaries of the waste site would ensure protection of the surface impoundments from the 100 year storm. Figure 13 shows the site and immediate vicinity and the hydrogeological structures ultimately recommended for the overall protection of the surface impoundments.

5.2 Dimensions and Configurations

The Phase I surface impoundments were built each as 5 acre triangular or rectangular ponds, 350 feet by 622 feet, with berms on all sides. These berms were designed to be eighteen feet across at the top, roughly five feet above the pond bottom with a 2:1 outer slope and keyed at least one foot below the pond surface (8).

5.3 Liner

The surface impoundment liners utilized in-situ clay. The geotechnical report recommended a minimum of two feet of clay on the pond bottoms.

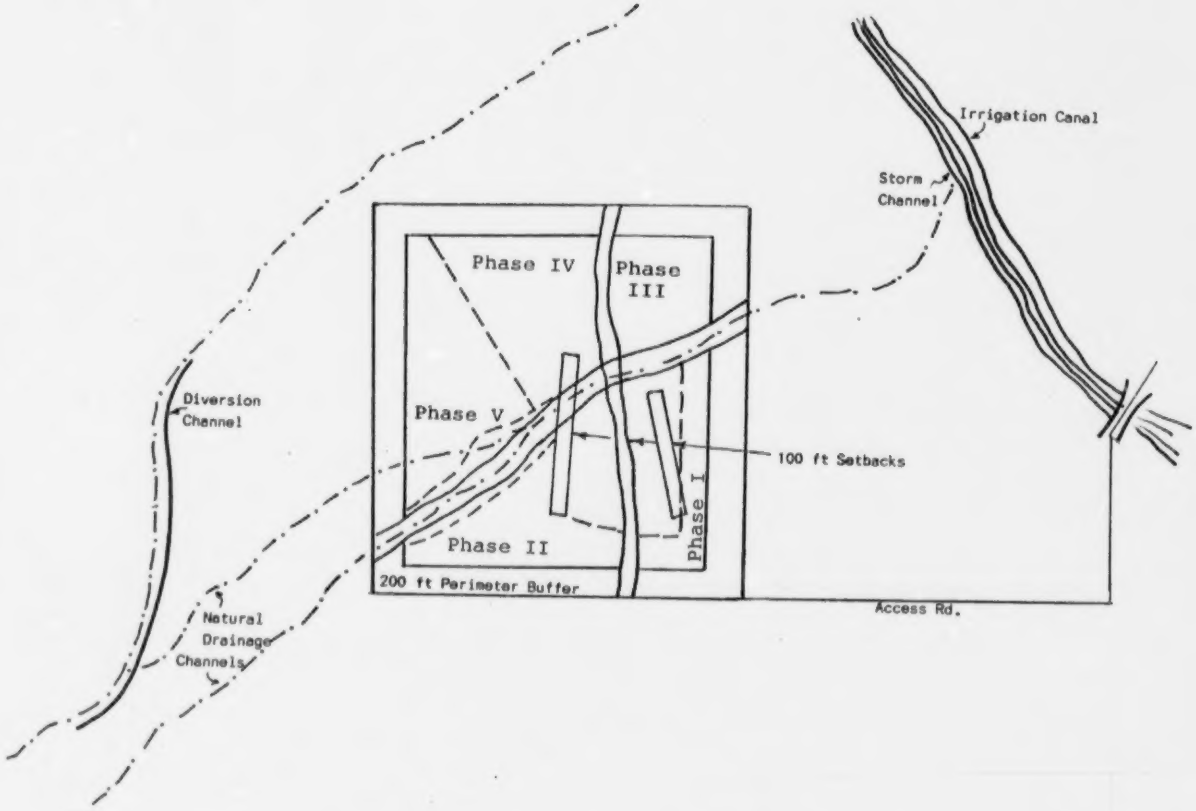

Irrigation Canal
Storm Channel
Phase IV
Phase III
Phase V
Phase I
Phase II
100 ft Setbacks
Diversion Channel
200 ft Perimeter Buffer
Access Rd.
Natural Drainage Channels

Figure 13. Site Area Showing Recommended Hydrogeological Improvements (7)

Compacted clay was to be used for the pond embankments and areas of the pond bottoms which did not contain two feet of natural clay (4).

5.4 Foundation Preparation, Leak Detection System and Backfilling

Excavation for the ponds was 3 to 5 feet below the ground surface. Berms were constructed of compacted clay excavated from a pond and other areas. They were placed parallel to topographic contours so that they would be perpendicular to any sheet flow of storm runoff. No leak detection system was installed; no backfilling was done.

5.5 Inlet/Outlet and Other Structures and Provisions

There were no inlets or outlets to the surface impoundments. Wastes were trucked to the site and pumped into the ponds from trucks. Outlets were not installed because the surface impoundments served as solar evaporation ponds.

5.6 Observation Wells and Monitoring System

There are seven on-site monitoring wells, each 100 feet deep, and one supply well (9). These wells are shown in Figure 14. Wells numbered 5, 6, 7 and 13 are currently being periodically sampled to provide water quality data to the state.

5.7 Quality Control/Quality Assurance Specifications

There was no record available of quality control specifications other than state soil permeability requirements. Inspectors from the geotechnical firms and the state were present at various times during and after construction; however, there are no written construction inspection reports available only letters certifying that the construction was done according to plans and specifications.

Soil permeability tests were recommended by the geotechnical firm at various stages in the construction of the surface impoundments to verify the minimum thickness and permeability of the natural clay soils within the pond areas and the density and permeability of compacted clays used in the embankments (4). Pond bottoms were tested after excavation by drilling to a maximum depth of 5 to 7 feet at regular intervals. Soil samples were assigned a permeability based on visual comparison with samples of known permeability obtained from previous studies at this site (10). Based on these findings, the soils beneath the ponds were reported to have a permeability less than the 1×10^{-6} cm/sec required by the state. Testing for pond bottoms was recorded for ponds 3, 5 and 8 (10,12). The construction firm in letters to the owner/operator indicated that the geotechnical firm inspected bottoms of ponds 5 and 8 (11). No record of the geotechnical firm's reports was available. State inspectors were on-site at various times to ensure compliance with state requirements but written reports were available documenting inspection of only the bottom of pond 8 (12). State inspection reports of site flood protection improvements were also available (12).

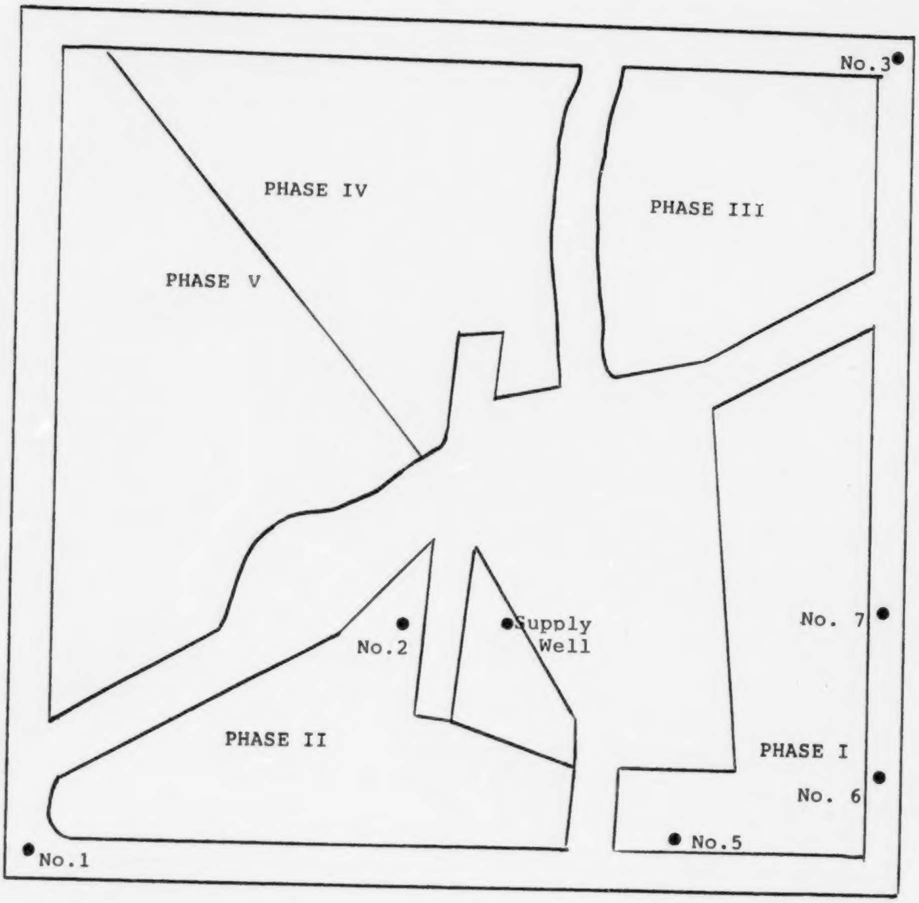

No.3
PHASE IV
PHASE III
PHASE V
Supply Well
No. 7
No.2
PHASE II
PHASE I
No. 6
No.5
No.1

Figure 14. Location of Monitoring Wells (9)

6.0 DEVIATIONS FROM DESIGN, PROBLEMS ENCOUNTERED DURING CONSTRUCTION AND COSTS

6.1 Deviations from Design

Minor field changes were recorded by the contracting engineers during construction. Bottoms for ponds 5 and 3 were lowered three feet for more clay to build the site. Parts of the containment berm for pond 8 were reported to be keyed to a depth greater than one foot.

6.2 Problems Encountered During Construction

There were apparently no major problems encountered during construction.

6.3 Level of Quality Assurance/Quality Control Competency

Since there were no construction inspection reports available (only mention that certain inspections were made) the competency of the inspectors could not be determined.

6.4 Cost Data

No cost data were available for this site.

7.0 PERFORMANCE DATA AND OPERATING EXPERIENCE

7.1 Liner Performance

The ponds were completed in early 1981. A routine state inspection in April 1981, reported that ponds 3 and 5 were being used for landfarming of oily wastes and that pond 8 contained liquids (13). There was four feet of freeboard and the embankments appeared to be in good condition. Another state inspection in May 1981, following an earthquake in the immediate area, also showed no problems (14).

During the July 1982 routine state inspection, however, damp soil was found at the exterior foot of the northeast and east containment berms of pond 8, indicating that the pond was leaking (15). The northeastern damp area was 22 feet in length. The eastern berm had three damp areas totaling about 75 feet in length. Figure 15 shows the position of these damp areas (16). Further inspection of the damp soil revealed no petroleum odor and the presence of salt crystals (17). It appeared that the berm had been leaking for several days and had recently surfaced due to humid weather. The rest of the berm appeared to be dry so the liquid was thought to have migrated from deep in the berm, leaking between the pond bottom and the berm bottom. Laboratory analysis of the damp soil supported the presumption that the damp areas were caused by liquid from the pond (17). The damp areas were wetter, saltier, and more acidic than background soils.

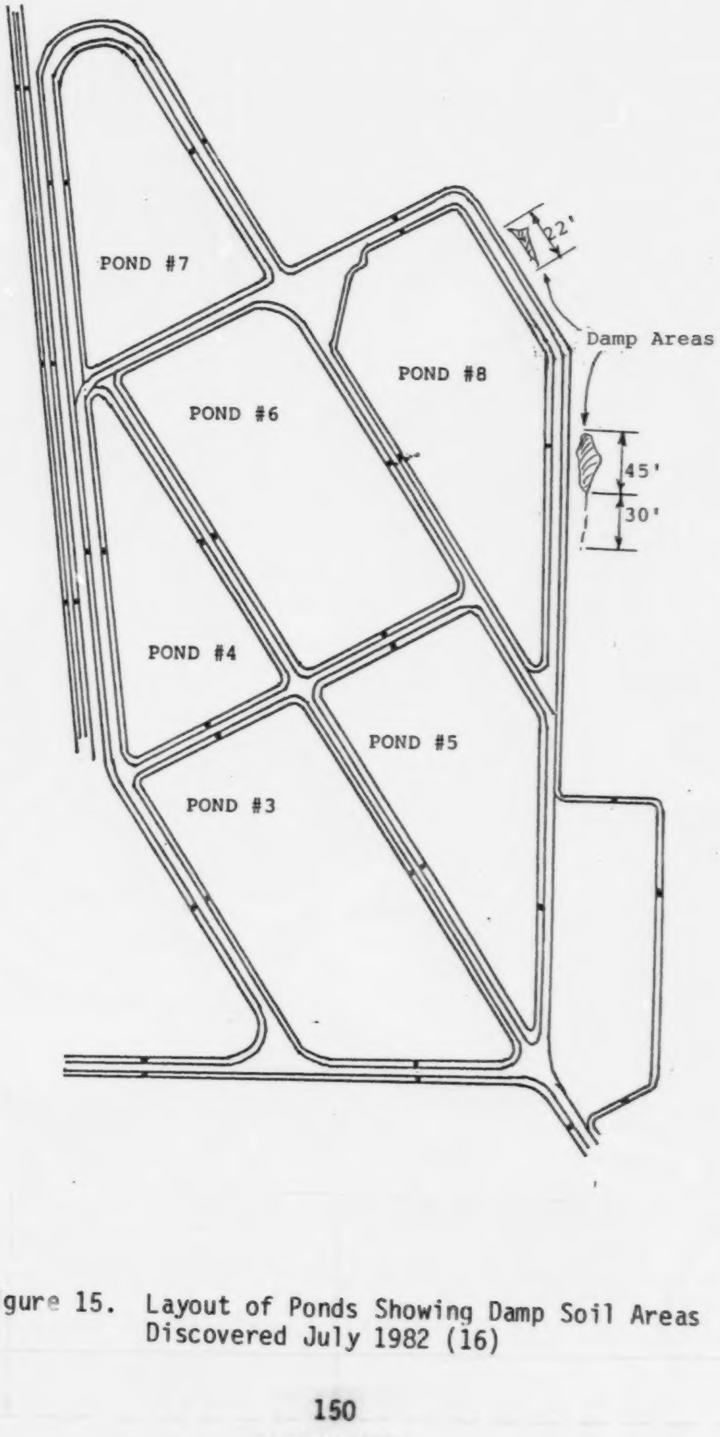

POND #7
22'
Damp Areas
POND #8
POND #6
45'
30'
POND #4
POND #5
POND #3

Figure 15. Layout of Ponds Showing Damp Soil Areas Discovered July 1982 (16)

Investigations reported by the owner/operator determined the cause of the leaks to be sandy-silt lenses extending under the berms providing a permeable pathway of migration of the pond liquids (18). Repair of the berm consisted of excavation of a 24 inch trench into the berm 12 to 13 feet, removal of the sandy-silt and refilling the trench with compacted clay. The repair trench is shown in Figure 16. The east berm trench was 200 feet long and the northeast berm was 100 feet long. The external damp soils were removed and placed in pond 5 and replaced with clean clay.

The state reported that the repair design was reasonable but needed some assurance that other leaks would not occur. The owner/operator was requested to conduct a leak detection survey outside of each pond (18). Before this survey was performed, a second leak occurred in November 1982 (19). Remedial action was planned prior to detection of the third leak found in May 1983 (20). In February 1983, the owner/operator had proposed to build a new external berm the full length of pond 8. In May 1983, after the third leak was found, the state requested that construction of the new berm begin at once and that a full investigation be made into the cause of the failure of pond 8 and an evaluation be made of the chance of failure for ponds 3 and 5 (21).

When a field investigation was made of ponds 5 and 8 by the consulting geotechnical engineering firm (report dated May 1983), old stream channels were identified that run through the pond areas (22). Borings were made in the berm at the points where these stream channels cross the pond. The borings for pond 8 are shown in Figure 17. In addition to the borings, an effort was made to locate construction inspection reports for Pond 8.

Sand deposits, and even one moist sand deposit, were located by the borings in pond 8 but not pond 5 (22). Based on the field investigation the geotechnical firm believed that pond 5 was satisfactorily keyed to natural impermeable clay material. However, this did not seem to be the case with pond 8, especially the east berm, for which adequate construction records could not be located (22).

The recommendation was made to build a subsurface impermeable barrier on the east side of pond 8 and ensure satisfactory keying to firm unweathered clay 3 to 6 feet below the ground, replacing any channel deposits with compacted clay (23). As stated previously, the correction that was carried out was to build a new berm. This berm incorporated the old one but was keyed to natural clay the entire length of the pond. This new berm has been in use for approximately one year with no apparent leakage problems (2). An analysis of the situation by the state indicates that the cause of the berm failure was inadequate construction inspection plus the possibility that the one foot or more keyway design criterion was not sufficient to ensure containment of the liquid waste (24).

REFERENCES AND DATA SOURCES

1. Operations Plan submitted to County, August, 1980.
2. Personal communication with state personnel, October, 1983.

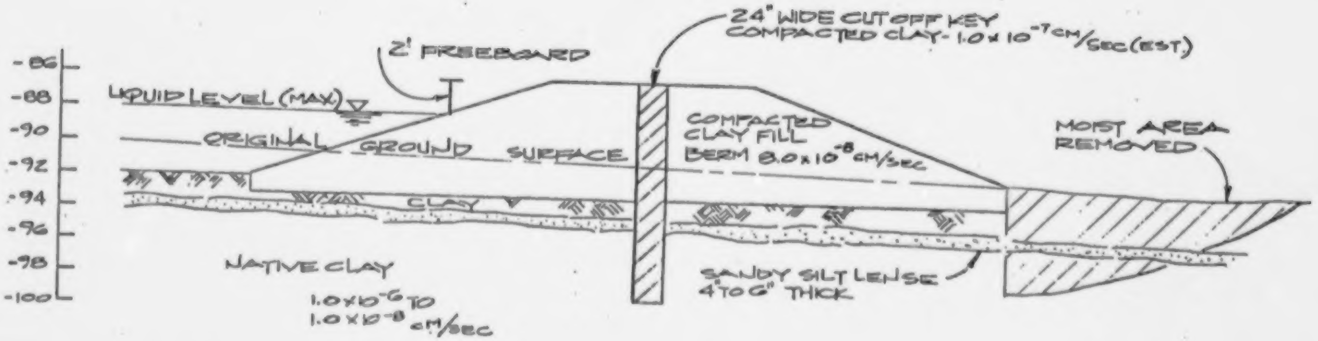

-86
-88
-90
-92
-94
-96
-98
-100
LIQUID LEVEL (MAX)
2' FREEBOARD
ORIGINAL GROUND SURFACE
CLAY
24" WIDE CUTOFF KEY COMPACTED CLAY- 1.0 x 10^-7 CM/SEC (EST.)
COMPACTED CLAY FILL BERM 8.0 x 10^-8 CM/SEC
MOIST AREA REMOVED
NATIVE CLAY
1.0 x 10^-6 TO 1.0 x 10^-8 CM/SEC
SANDY SILT LENSE 4" TO 6" THICK

Figure 16. Trench to Repair Leaks in Pond 8 (16)

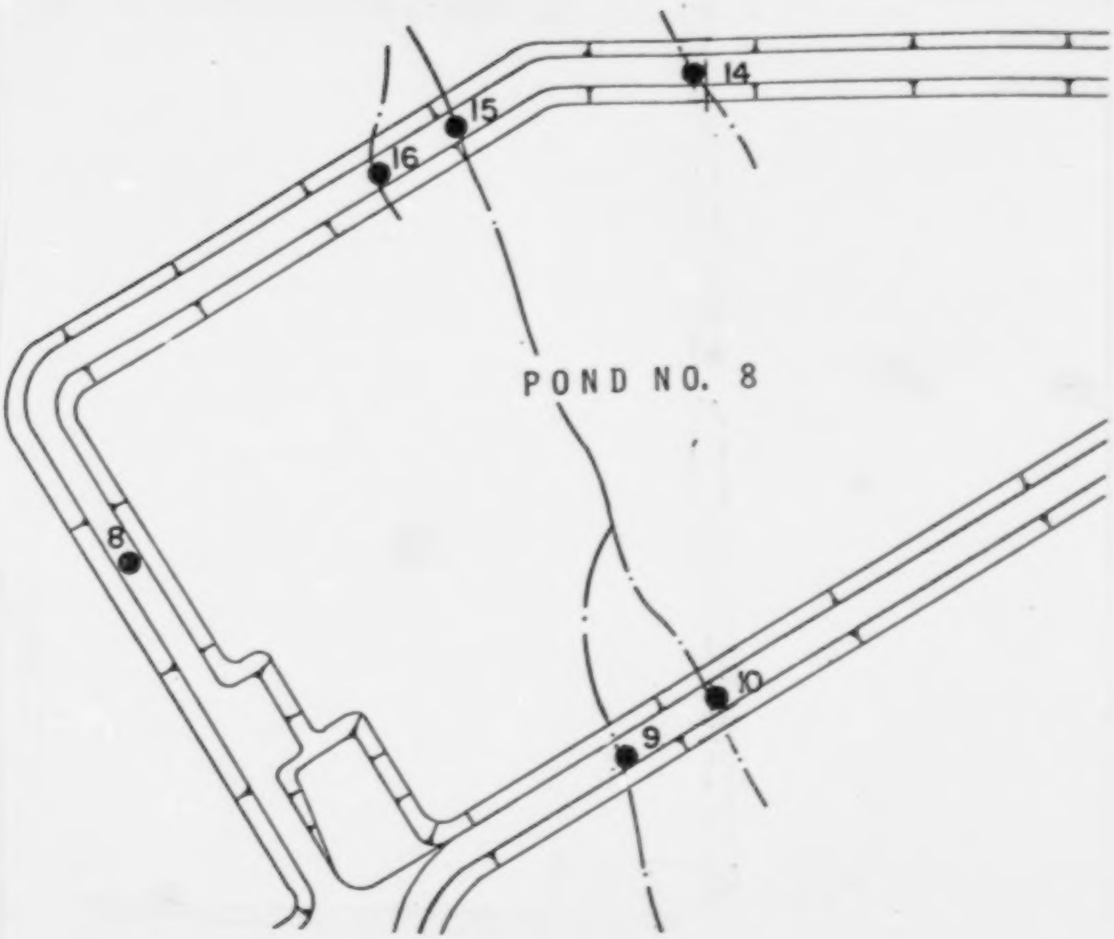

14
15
16
POND NO. 8
8
10
9

Figure 17. Pond 8 Showing Borings at Intersection with Old Stream Channels (22)

3. Report of Sampling and Analysis of Pond Contents by the state, April, 1981.
4. Report of Geotechnical Investigation by geotechnical firm, January, 1980.
5. State Waste Discharge Requirements, 1981.
6. Waste Receipts for 1981 sent to state.
7. Letter report to state, January, 1981.
8. Design Criteria, Master Plan, May, 1980.
9. Completion Report on Monitoring Wells by geotechnical firm, March, 1981.
10. Results of permeability determinations for ponds 5 and 8, January, 1981.
11. Letters from construction firm, December 1980 and January, 1981.
12. State site inspection report, February, 1981.
13. State site inspection report, April, 1981.
14. State site inspection report, May, 1981.
15. State site inspection report, August, 1982.
16. Letter describing corrective action, August, 1982.
17. Report of soil analysis by state, August, 1982.
18. Internal state memo, September, 1982.
19. Letter from state, February, 1983.
20. Letter to state, February, 1983.
21. Letter from state, May, 1983.
22. Results of exploratory drilling by geotechnical firm, May, 1983.
23. Letter to state, June, 1983.
24. Internal state memo, February, 1983.
25. Discussions with owner's environmental staff, November 28, 1983.

CASE STUDY NO. 7

1.0 GENERAL DESCRIPTION AND HISTORICAL BACKGROUND

This large fertilizer production complex is situated in an alluvial plain in the Southeast and adjacent to a large river. There are a number of other chemical manufacturing plants in the general area which is surrounded by farm lands. The subject production complex consists of facilities which produce ammonia, urea, ammonium phosphate, sulfuric acid and phosphoric acid. The ammonia, urea, and ammonium phosphate production facilities have been in operation since 1968. Production facilities for sulfuric and phosphoric acids were completed in 1975 along with an expansion of the ammonium phosphate production capacity. Since all wastes generated result from mining and ore (phosphate rock) processing and hence subject to the temporary mining waste exemption of RCRA (40 CFR 261.4(b)(6)), the gypsum pond water and cooling pond wastewater would not be technically hazardous for regulatory purposes. Had it not been for this exemption, these wastes would be hazardous by virtue of its corrosivity.

As shown in Figure 18, the surface impoundments at this facility consist of two gypsum ponds and a cooling pond. The 150-acre "initial" gypsum pond and the 200-acre "expansion" gypsum pond were constructed in 1974 and 1980, respectively. Slurried gypsum, from the phosphoric acid plant, is pumped to these ponds where it settles out. The clarified water is decanted and returned to the plant. Pond edge heights are increased by stacking the gypsum with a dragline. This allows additional slurry deposition. Decant water, seepage through the gypsum dikes, and incident rainfall runoff are collected in ditches around the disposal facility perimeter. The 100-acre cooling pond, located adjacent to the gypsum ponds, has been used to cool process water from the phosphoric acid plant since 1974.

2.0 BASIS FOR SITE SELECTION

The initial gypsum and cooling ponds were located on site based on the results of a feasibility study and a subsequent geotechnical investigation. (An additional geotechnical study was also later conducted in the expansion gypsum pond area.) These studies included site inspection, test borings, laboratory testing (unconfined and triaxial compression tests, Atterburg limits, sieve analysis, and consolidation tests), and computerized soil stability analysis. The overall objective of the geotechnical studies was to insure that sufficient and suitable storage volume was available on roughly 600 acres of accessible land (owned by the company) to provide for plant operation through the year 2000.

Pond construction timing in relation to the Federal water quality regulation development effort was such that this facility became the "model" for on-land gypsum disposal in the state.

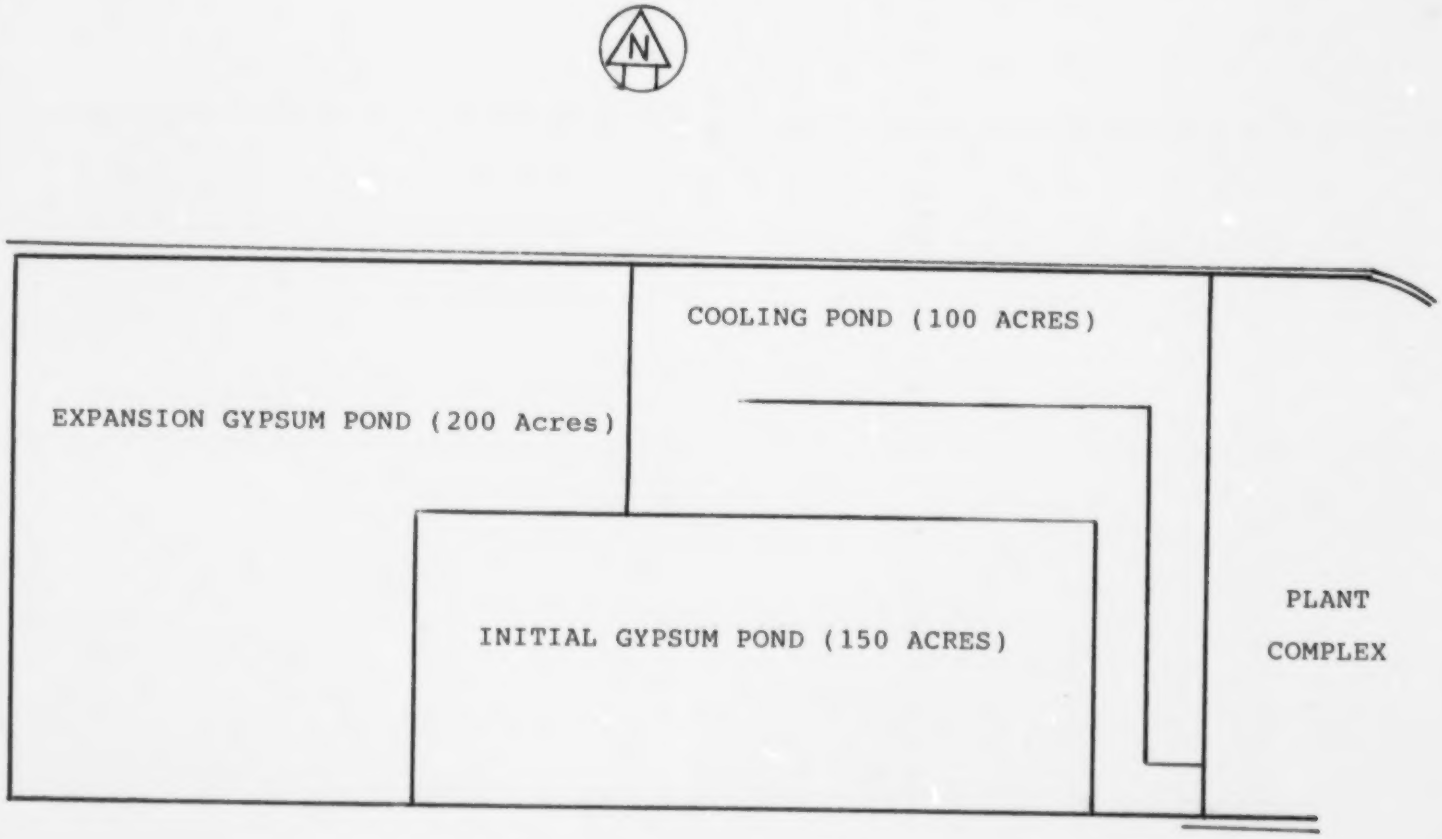

N
COOLING POND (100 ACRES)
EXPANSION GYPSUM POND (200 Acres)
INITIAL GYPSUM POND (150 ACRES)
PLANT
COMPLEX

Figure 18. Plant Pond System Layout

3.0 DESIGN, CONSTRUCTION, AND INSTALLATION FIRMS UTILIZED

All ponds were designed by the same geotechnical consulting firm in cooperation with the owner. The owner selected this particular geotechnical consultant because they are a local firm familiar with gypsum impoundment design and have extensive working experience with the soils in the area. The particular construction contractor was chosen because of its experience and reputation.

4.0 DESIGN CRITERIA

4.1 Purpose of Impoundments

The initial and expansion gypsum ponds were designed to accommodate gypsum disposal above ground. Internal clay-starter dikes initially contain the gypsum slurry as it first enters the ponds. Water is decanted and returned to the plant. Pond edges are increased in height by stacking with a dragline. This allows continued gypsum slurry disposal. The cooling pond recirculates cooling water from the phosphoric acid plant.

4.2 Process Description and Wastewater Characteristics

In the phosphoric acid plant, ground phosphate rock and sulfuric acid are fed to the reactor which contains a slurry of gypsum solids in phosphoric acid. These are the products of the rock-sulfuric acid reaction. A large amount of heat is liberated in the reactor. Reactor residence time is four to five hours. Slurry is continuously withdrawn and filtered to separate the gypsum from the phosphoric acid. The gypsum is distributed to the gypsum ponds via 20-inch flexible polyethylene lines, after being thoroughly washed with water to recover all the phosphoric acid. Process water is sent to the cooling pond via a 36-inch diameter discharge pipe and subsequently returned to the phosphoric acid plant.

An analysis of gypsum slurry and cooling pond process water is provided in Table 32. As seen in the table, the waters are acidic (pH < 2) and contain substantial amounts of phosphates, fluorides, and solids.

4.3 Service Life

The cooling and gypsum ponds are situated so as to permit future expansion to the west (see Figure 18). The approach for the gypsum ponds was to achieve a maximum life span which is dependent on the height to which the pond can be raised. The height of the pond is determined by the strength of the foundation soils, especially the in situ clay. The strength of the clay is low but will increase as the clay consolidates under the gypsum pile loads. Therefore, the maximum height to which the pile can be raised depends on the rate of strength increase in the clay. The silt and sand strata contained in the clay will provide drainage paths allowing the clay to consolidate more quickly.

TABLE 32. ANALYSIS OF GYPSUM SLURRY AND COOLING POND WATER

Element	Cooling Pond ug/l	Gypsum Slurry
Silver	<4	57 ug/kg
Arsenic	3,020	2,950 ug/kg
Beryllium	59	63 ug/kg
Cadmium	221	210 ug/kg
Chromium	1,379	2,700 ug/kg
Copper	299	855 ug/kg
Nickel	2,496	3,050 ug/kg
Lead	2,000	360 ug/kg
Antimony	77	115 ug/kg
Selenium	<2.7	<200 ug/kg
Thallium	<80	85 ug/kg
Zinc	2,330	4,100 ug/kg
pH	<2	---
TSS	323,000	220,000,000 ug/l
Total P	6,300,000	---
Ammonia	513,000	---
Fluorides	11,000,000	---
COD	303	1,100,000 ug/l
Calcium	801	729,000 ug/l
Magneseium	200	67,000 ug/l
Sodium	1,000	457,000 ug/l
Aluminum	212,000	13,800,000 ug/l
Manganese	11,800	3,870 ug/l
Vanadium	5,180	949 ug/l
Boron	23,000	210 ug/l
Barium	205	50 ug/l
Molybdenum	687	<150 ug/l
Tin	1,210	<600 ug/l
Cobalt	696	220 ug/l
Iron	145,000	54,800 ug/l
Titanium	1,960	592 ug/l

The successful operation of the gypsum ponds requires field monitoring to detect horizontal movement and pond water pressure of the foundation soils beneath the ponds. The geotechnical consultant cautioned that predicted service lives are subject to revision based on evaluations of information obtained from the field monitoring system. The useful service life of the cooling pond was not evaluated by the geotechnical consultant.

4.4 Site Hydrogeology

The ponds are located approximately 3000 feet west of the nearby river. From the flood control levee on the river's west bank to bayous west and north of the site, surface elevation varies between 17 and 12 feet, sloping downward to the west (away from the river) as a result of the river's natural levee. The predominant surface drainage feature is an interceptor canal, located along the north property line. Ground water, for all practical purposes, is at the site surface and, depending on seasonal rainfall, may fall to a maximum of 10 feet below the surface.

The area's average annual rainfall is approximately 60 inches with the worst recorded annual rainfall of 93 inches. The evaporation rate is approximately 48 inches, which leaves about 12 inches of excess rainfall per year. From December through February, a maximum of 35 inches of rainfall may be expected with evaporation occurring at the rate of only 1 inch per month. Single storm rainfall intensites of 5 inches per hour and 14 inches per day correspond to 25 year and hurricane storms, respectively.

In general, the subsurface profile consists of three strata of pleistocene origin. The deepest of these, located about 120 feet below ground surface, is composed of dense to very dense fine sand. This layer is termed the substratum sand. Overlying this to a depth of 20 to 30 feet below ground surface is a layer consisting mainly of soft to medium clay. This stratum termed backswamp clays contains some pockets and layers of silt and sand. Backswamp clays are predominantly high plasticity clay and normally consolidated. The top most layer on the site is the present day natural levee. The natural levee deposits are mostly medium to low placticity clay, but do contain some sand and silt lenses. The stratum is relatively coarse close to the river, grading increasingly finer further away from the river bank.

In the area of the initial gypsum pond, layers of sand and silt contained in the clay stratum are most prevalent in the eastern one third of the pond and are almost completely lacking in the southwest corner. Sand and silt lenses exist close to the surface in the northwest corner of the cooling pond.

Expansion gypsum pond soil conditions are similar to those underlying the initial construction with two exceptions. First, the dense sand layer is 20 to 30 feet deeper than before. Second, there is a greater percentage of sand and silt lenses in the upper clay layers than found previously.

The substratum sand deposit provides fresh water primarily for industrial and agricultural use in the area. Some domestic offtake also occurs. Below approximately 260 feet, the water becomes brackish. The substratum sand is directly connected to the nearby river. Water levels consequently fluctuate with river stage variation even becoming artesian during flood stage. Direction of groundwater flow is generally west to southwest, away from the river. This may be reversed during low river stage.

The closest supply wells to the ponds are plant owned. There are no nonplant owned wells located within 2500 feet of the ponds.

4.5 Waste-Liner Compatibility

No waste-clay compatibility testing was required or performed.

4.6 Soil Permeability

The in situ clay's vertical permeability is approximately 10^{-9} cm/sec. Clay horizontal permeability could be as much as 10 times greater due to the local area alluvial depositional mechanism (seasonal sedimentation resulting in horizontal stratification). The silt lenses in the natural levee stratum have permeabilities in the 10^{-4} cm/sec range. By comparison with the clay, these silt lenses are free draining.

4.7 Regulatory and Permit Requirements

Since rainwater falling on the gypsum and cooling ponds is immediately contaminated, it must, by NPDES regulation, be contained and treated before being released from the confines of the plant.

The owner initially applied for an interim status permit for the ponds under the state's hazardous waste management plan. Under this plan, the owner was required to: (1) control runoff as described above; (2) control runoff outside the ponds; (3) protect ground water by a barrier along the pond bottom and sides consisting of 3 feet of clay with $\leq 10^{-7}$ cm/sec permeability and resistant to action of elements and contents of the pond for the estimated service life; (4) monitor ground water; and (5) provide site hydrogeological data, operations plan, and closure plan. The entire category of gypsum was removed from the state's hazardous waste regulations.

The owner presently is regulated by the state's solid waste and water quality departments.

4.8 Cost Considerations

Locating the cooling pond adjacent to the gypsum ponds reduces costs and provides operational flexibility in containing gypsum stack fluids, cooling waters, and incident rainfall.

5.0 DESCRIPTION OF DESIGN AND DESIGN SPECIFICATIONS

The primary design objectives for the surface impoundments at this facility were to ensure: (1) impermeability of all pond bases and dikes (i.e., maintain the integrity of the existing in situ clay), and (2) gypsum embankment slope stability (stemming from foundation soil characteristics).

5.1 Initial Gypsum and Cooling Ponds

The cooling pond and gypsum pond site layout provides for the maximum usage of the land area available. Normal plant operation results in a maximum of 8,000 gallons per minute of water being returned from the gypsum pile to the plant. The cooling pond has a maximum of 40,000 gallons per minute flow to the plant. This 100-acre pond size was governed by cooling requirements rather than flow requirements.

Of major concern in the design and construction of the cooling pond was potential seepage beneath or through the cooling pond dikes. Since very little vertical seepage is expected through the clay, the severity of seepage problems will depend on whether or not sand and silt strata are exposed during pond construction. The following construction sequence was specified in the design to eliminate potential seepage conduits (see Figure 19):

- Before placing any fill, all organic matter, roots, sand pockets, etc., shall be removed to locations specified by the owner. The depth of stripping varies; about 18 inches will be normal to remove all debris.
- The base of the dike should also be stripped. The subgrade should then be checked to insure that no sand or silt layers are exposed. Any such layers that extend completely under a dike should be excavated to clay and a key installed.
- Fill for the dikes may be obtained from the cooling pond area; however, a 50-foot wide bench shall be left between any borrow areas and the interior toe of all exterior cooling pond dikes. This is to lengthen and possibly eliminate the flow path of water through any such discontinuous strata inadvertently encountered.
- The borrow excavation is to be a maximum of 5 feet in depth. Such a measure will reduce contact with surface silt layers.
- A 2-foot clay layer should be placed over all silt and sand strata exposed during stripping, borrow, or ditching operations. Before placement of any fill material, the area and material must be approved by the soils engineer.
- Clay for the dike should be placed in loose lifts not to exceed 12 inches and walked in with a D-7 or larger dozer eliminating void spaces. The clay must have a plasticity index ≥ 10.
- All elevations of ditches and dikes shall be adhered to strictly. The soils engineer shall determine when site conditions are again suitable for work following periods of inclement weather.

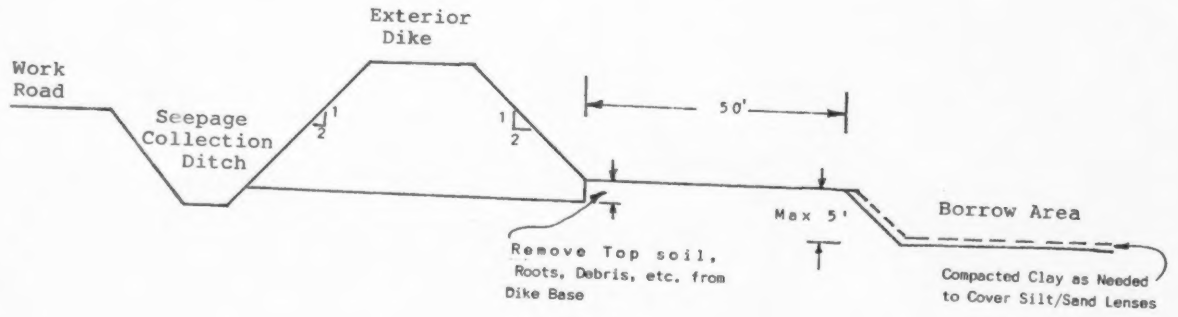

Work Road
Seepage Collection Ditch
Exterior Dike
1
2
1
2
50'
Max 5'
Borrow Area
Remove Top soil, Roots, Debris, etc. from Dike Base
Compacted Clay as Needed to Cover Silt/Sand Lenses

Figure 19. Schematic of Cooling Pond Exterior Dike Construction

The dike crest and bottom elevations of the cooling pond were established to insure as much balanced cut and fill as possible. This had to be consistent with a 3-foot operating water depth, a 3-foot surge depth, and 5-feet of dike freeboard. The resulting dikes are 11 feet in height with 2:1 (H:V) slopes.

The gypsum pond requires an internal starter dike to initially contain the gypsum slurry, a gypsum return ditch dike, and an outermost seepage collection ditch dike. The gypsum pond and dikes were designed and constructed in a manner similar to that previously discussed for the cooling pond, except that no 50-foot bench was required.

The gypsum pond is divided into three 50-acre plots by constructing interior partition levees from gypsum. This allows one plot to be used for deposition of gypsum and one plot for storage of rainwater, while the third plot is being prepared to receive gypsum. The gypsum piles are carried to the elevations shown in Figure 20 as determined by slope stability analyses.

By federal and state environmental codes, a system of ditches is required to intercept and contain all rainfall runoff from the ponds. The system of ditches consists of four parts. The first is a ditch paralleling the north property line that intercepts all runoff approaching the plant from the north. Part two consists of a plant site draining ditch. The third part consists of the cooling and gypsum pond seepage collection ditches. The last part is the gypsum water return ditch which runs between the two ponds and returns water from the gypsum pond to the plant.

Runoff from the ponds is directed via the seepage collection ditches to a liming plant. Treatment of rain water and discharge to the river is necessary at times due to the rainfall versus evaporation imbalance.

5.2 Expansion Gypsum Pond

The gypsum pond expansion was necessary because the initial 150-acre gypsum stack reached its safe (from a stability standpoint) height in 1980 (approximately 50 feet above ground level) and was temporarily abandoned. Leaving the pond idle for a time was thought to permit an increase in the subsoil strength as the overlying gypsum load squeezes water from the subsurface clay.

Dikes at the edges of the pond fall into three categories: seepage collection ditch dikes, gypsum return ditch dikes, and gypsum pond starter dikes (see Figure 21). The following specifications/steps were followed in constructing impoundment base and dike:

- Locate and stake all dike centerlines and toes. Stake interior 50-foot wide seepage bench toe.
- Remove all surface organics, silt and sand down to clay from dike bases. If an excessive depth of sand or silt is encountered, a minimum 2-foot compacted clay cutoff wall can be constructed under dike centerline down to clay.

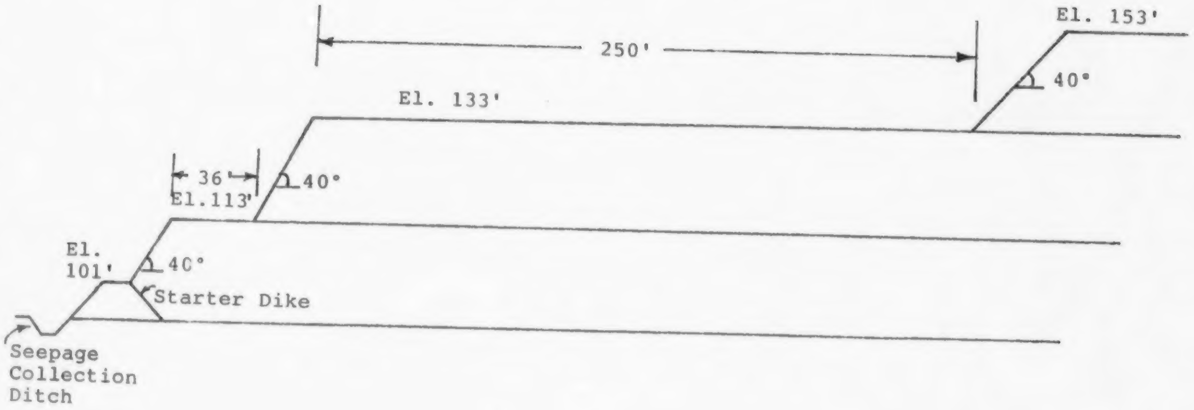

El. 153'
250'
40°
El. 133'
36'
El.113'
40°
El.
101'
40°
Starter Dike
Seepage
Collection
Ditch

Figure 20. Schematic of Gypsum Pond Side Slopes

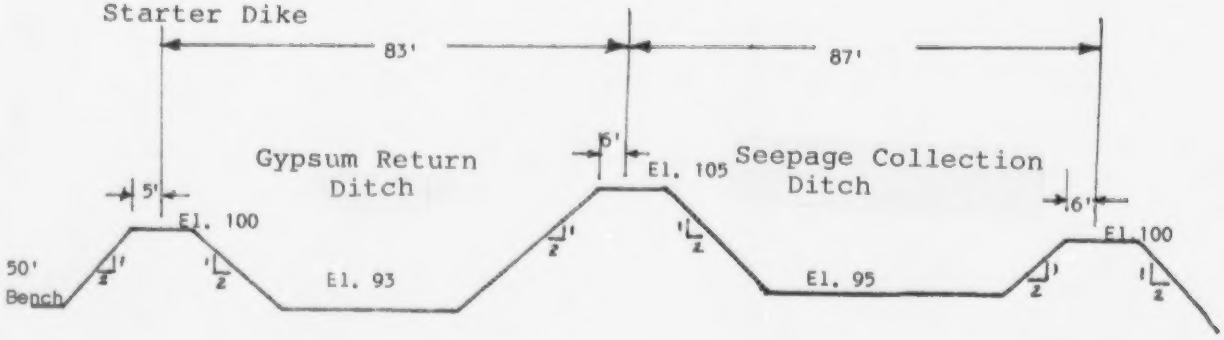

Starter Dike
83'
87'
5'
5'
6'
El. 100
El. 105
El. 100
Gypsum Return Ditch
Seepage Collection Ditch
50' Bench
El. 93
El. 95
1'
2

Figure 21. Expansion Gypsum Pond Detail

- Scarify and recompact exposed clay (top 6 inches). Inspect compaction. Place and compact clay to maximum 6-inch thick finished lifts. Compaction should consist of 3 passes by a D-7 size dozer or larger and be controlled by a soils technician. The requirement is to eliminate void spaces that will pass water.

- Avoid over-excavating ditch bottoms to prevent exposing underlying sand or silt layers.

- Dress and seal all dikes by walking and back-blading with a dozer. Dike surfaces may be seeded to enhance foliage growth for erosion protection.

- Construct outfall structures.

- Tie-in to existing pond system and install monitoring instrumentation.

The maximum gypsum stack crest elevation as determined by stability analysis represents a 50-foot gypsum thickness. Maximum consolidation vertical movements, occurring with time as pore water is squeezed out of the clay soil, will be about 36 inches at the center and 18 inches at the edge over a 5-year period. As determined by subsoil deformation analysis, this represents about 50 percent of the ultimate possible consolidation settlements.

5.3 Monitoring Systems

The successful operation of both gypsum and cooling ponds requires field monitoring. To accomplish this, a monitoring system consisting of observation wells to detect any contamination of the ground water from the ponds, inclinometers to detect horizontal movement of the foundation soil beneath the gypsum ponds, and piezometers to measure pore water pressure were installed. Leak detection systems are not used at this facility.

Since the clays in the upper 120 feet of the soil profile have very low permeabilities, the potential for migration of pollutants to the deep aquifer is extremely low. The more permeable lenses of silt and sand in the upper 10 to 20 feet of the soil profile may, however, act as zones of lateral seepage; thus, ground water monitoring was required for these lenses.

Six ground water monitoring wells were installed around the perimeter of the initial gypsum and cooling ponds in 1973. Samples from these wells are routinely analyzed for pH, phosphate, and fluoride content. The state required an additional 14 wells to be installed in November, 1981. Of these total of 20 wells, 19 are located on the containment dikes surrounding the gypsum and cooling ponds. The other well is located about 2000 feet northeast of the cooling pond and is for background water quality sampling. Beginning in 1982, samples from all of the monitoring wells are now analyzed for heavy metal, inorganic species, and radio-nuclides content.

Many inclinometers and standpipe piezometers have been installed along the edges of the gypsum stacks. Measurements are made on a routine basis.

5.4 QA/QC Specifications

The geotechnical consultant inspected the construction of all ponds. Inspection of foundation preparation amounted to insuring that the dikes would be placed on either non-organic clay or over a minimum 2-foot wide compacted clay cut-off trench. The chief requirement for compaction was to eliminate the larger voids and achieve a permeability less than 1 x 10^{-7} cm/sec (the maximum allowed by EPA). The primary objective of dike systems inspection was to insure the dike's water tightness; of secondary interest was the dike's structural integrity (their ability to support gypsum handling equipment).

The geotechnical inspection was handled by an onsite technician observing the construction contractor's activities. Field testing involved some inplace density determinations to initially check the dikes material's compaction. Atterburg limit determinations were run to insure that only clay material was used. Laboratory analysis included modified Proctor compaction tests to serve as standards for the in-place density checks. Also, undisturbed clay samples were subjected to falling head permeability testing.

The technician's daily onsite observations and results of field and lab tests were documented. Engineering site inspections periodically augmented the technician's observations.

Observed dike base preparation, borrow pit locations and excavation procedures, and dike construction material all conformed to the job specifications. Measured dike permeability averaged close to 10^{-8} cm/sec. The compaction technique has imparted to all dikes sufficient structural integrity to support anticipated pond management traffic. All inspection work is documented in geotechnical reports beginning in February 1974.

6.0 DEVIATIONS FROM DESIGN, PROBLEMS ENCOUNTERED DURING CONSTRUCTION, AND COSTS

Since the expansion gypsum pond dikes were built over a 5-1/2 month period, drying of the clay has occurred. Consequently, some desiccation cracks formed in the clay. These cracks permit water flow until the clay rehydrates and swells to close them. At pond startup, a slow raising of the pond water level was recommended by the geotechnical consultant. This would close cracks and prevent leakage through them. Also, during the first 4 weeks immediately following startup, all dikes were inspected for leaks by the owner.

No problems other than the desiccation cracking noted above were encountered during construction.

The cost for the original gypsum pond was $910,000 in 1973. Expansion of the pond system costed $1,150,000 in 1979.

7.0 PERFORMANCE DATA AND OPERATING EXPERIENCE

7.1 Monitoring Results

As stated previously, since the clays in the upper 120 feet of the soil profile have very low permeabilities, the potential for migration of contaminants to the deep, substratum sand aquifer is extremely low, and any seepage that might occur would be insignificant. Further, since there are seasonal fluctuations in the rate and direction of ground water flow within the aquifer, and since the nearest known non-plant wells tapping this aquifer are about 2,000 feet away upgradient and over 5,000 feet away downgradient from the facilities, the potential for migration to known water wells is also very low. This is substantiated by information obtained from company-owned supply wells which are the closest wells to the ponds. Intermittent monitoring of the water quality of these wells by the owner has yielded no indication of the contamination of the deep aquifer.

Possible lateral seepage of contaminants to nearby natural or man-made drainage courses via sand and silt lenses was the impetus for the establishment of a network of shallow monitoring wells. Water quality data from the shallow ground water monitoring wells are given in Tables 33 through 35. Table 33 is a chronology of indicator parameter levels in the wells established before the ponds became operational. Table 34 is an example of the water quality used to establish baseline levels for the 14 newer wells. In Table 35, only the indicator parameter levels are listed for the newer wells.

As seen in Table 33, there appears to be no significant trends (increases or decreases) in the parameter levels among any of the older wells. Also, initial background levels of indicator parameters for the newer wells indicate little or no lateral migration has occurred. This is strong evidence that the ponds and dike systems are effectively containing the impounded waters. Furthermore, comparing standpipe piezometer level increases with constant readings from the monitoring wells indicates the gypsum ponds effect on the ground water table surface is extremely localized. At even slight distances from the pond, the ground water potentiometric surface is essentially unaffected. The reasons for this are the highly impervious nature of the clay on which the gypsum ponds are constructed coupled with the localized nature of the granular layers (actually pockets).

7.2 Gypsum Stack Failure

A massive failure of the old 100-acre gypsum stack occurred on 15 April 1983. In December 1978, and again in May and October 1979, smaller landslides were observed at the old gypsum stack. These failures have not only changed ongoing gypsum disposal operations, but have set trends for future design and operation practices. The cause of these failures, an

TABLE 33. OBSERVATION WELL DATA

Well No. 1 - Northwest Gypsum - Cooling Pond

Date	pH	P(mg/l)	F(mg/l)	Depth of Water
9/17/74	10.3	0.4	0.6	-
9/30/74	11.6	0.2	0.5	-
10/14/74	8.4	1.3	0.3	-
11/26/74	11.7	0.1	0.4	5' 10"
Started Using Ponds 3/2/75				
5/22/75	8.2	0.2	0.4	-
11/28/76	11.8	0.2	0.3	-
3/21/77	11.7	0.7	0.3	4' 6"
4/14/77	11.8	0.7	0.4	5' 3"
5/18/77	11.5	0.8	0.2	5' 5"
6/27/78	11.0	0.7	0.4	5' 7"
2/27/79	9.5	1.1	0.2	6' 10"
9/24/79	11.7	0.7	0.2	5' 1"
12/ 2/79	12.2	1.0	0.6	-
2/25/80	11.0	1.1	0.4	6' 3"
3/ 8/82	8.1	2.1	2.35	-
5/18/82	6.9	0.1	0.15	-
8/31/82	6.9	0.1	0.17	-
11/ 9/82	7.6	0.06	1.6	-

Well No. 2 - Northeast Gypsum - Cooling Pond

Date	pH	P(mg/l)	F(mg/l)	Depth of Water
9/17/74	10.6	4.4	0.5	-
9/30/74	10.0	0.2	0.6	-
10/14/74	9.0	1.5	0.4	-
11/26/74	7.6	5.0	0.4	2' 1"
Started Using Ponds 3/2/75				
5/22/75	7.6	0.5	1.7	-
6/18/75	7.4	0.5	0.8	-
3/21/77	8.4	2.9	0.6	8"
6/24/77	8.9	1.1	0.8	1' 1"
2/15/78	8.0	0.9	0.4	-
9/24/79	9.2	1.0	0.5	7"
2/25/80	8.9	1.2	0.3	2' 4"
3/ 8/82	10.7	0.43	0.11	-
5/18/82	8.7	0.07	1.2	-
8/31/82	7.9	0.34	0.37	-
11/ 9/82	7.4	0.45	0.29	-

(Continued)

TABLE 33. OBSERVATION WELL DATA (Continued)

Date	pH	P(mg/l)	F(mg/l)	Depth of Water
Well No. 5 - South Gypsum Pond				
11/26/74	9.4	0.4	0.4	8' 5"
Started Using Ponds 3/2/75				
6/24/77	7.4	1.0	1.3	10' 9"
10/21/77	6.8	1.0	0.8	10' 8"
3/29/79	6.5	2.6	2.1	10' 3"
3/8/82	7.4	0.5	0.42	-
5/18/82	6.8	0.2	0.6	-
8/31/82	6.6	1.0	0.49	-
11/ 9/82	6.3	0.45	0.5	-
Well No. 6 - East Gypsum - Cooling Pond				
9-17/74	7.6	1.0	0.5	-
10/14/74	7.0	1.8	0.3	-
11/26/74	7.4	0.8	0.3	-
Started Using Ponds 3/2/75				
6.18.75	6.5	0.8	0.6	-
3/21/77	6.8	0.8	0.3	5' 4"
6/27/78	6.7	1.1	0.2	5' [illegible]
2/27/79	6.8	1.0	0.3	3' 10"
9/24/79	7.0	1.0	0.5	5' 9"
2/25/80	6.7	1.3	0.3	5' 10"
3/ 8/82	7.6	0.24	0.21	-
5/18/82	6.7	0.24	0.39	-
8/31/82	6.6	0.96	0.41	-
11/ 9/82	6.5	0.25	0.42	-

TABLE 34. WATER QUALITY DATA FOR WELL NO. 8

	3/8/82	5/18/82	8/31/82	11/9/82
Specific Cond., umhos/cm^2	1,700	1,100	880	1,300
pH	12.7	11.5	11.8	6.8
Temperature, °C	19°	21°	27°	25°
TDS, mg/l	828	3,944	500	732
TSS, mg/l	356	25	6.3	2.7
TS, mg/l	1,184	3,969	506	735
Settl. Solids, mg/l	125	2.5	<0.1	<0.1
D.O.C., mg/l	5	3	<1	12
Phenol, mg/l	<0.001	<0.001	0.008	0.004
NH_3-N, mg/l	0.7	0.8	1.4	3.1
Chlorides, mg/l	27	26	25	31
CN, mg/l	0.08	0.022	<0.002	<0.004
F, mg/l	1.15	1.4	1.2	0.6
NO_3, mg/l	<0.005	0.21	0.035	0.006
P, mg/l	5.0	0.037	0.96	0.15
Ortho. P, mg/l	4.8	0.018	0.83	0.18
SO_4, mg/l	99	160	930	248
Sb, mg/l	<0.20	<0.15	<0.1	<0.1
As, mg/l	<0.226	0.046	0.065	0.027
Ba, mg/l	0.29	<0.08	<0.10	0.14
Be, mg/l	<0.005	<0.010	<0.01	<0.01
Cd, mg/l	0.016	<0.006	<0.005	<0.005
Cr, mg/l	0.101	<0.014	<0.01	<0.01
Cu, mg/l	0.072	<0.015	<0.01	<0.01
Fe, mg/l	69	0.06	0.03	0.76
Pb, mg/l	<0.10	<0.05	<0.04	<0.04
Mg, mg/l	30	0.034	1.1	26
Mn, mg/l	1.7	0.010	<0.01	0.94
Hg, mg/l	0.0004	0.0011	<0.0002	<0.0002
Ni, mg/l	0.111	<0.031	<0.03	<0.03
Se, mg/l	0.026	0.028	0.012	0.010
Ag, mg/l	0.012	<0.006	<0.01	<0.01
Na, mg/l	39	38	35	40
Tl, mg/l	0.13	<0.10	<0.03	<0.03
V, mg/l	0.29	<0.20	<0.1	<0.1
Zn, mg/l	0.313	<0.005	<0.01	<0.01
Radium, Pci/l	0.17	<2	<2	<2
Gross Alpha, Pci/l	1.41	3.3	11.0	<2
Gross Beta, Pci/l	14.00	9.1	<2	<2
Water Level (Plant Elev.)	89.46'	90.09'	90.67'	89.92'

TABLE 35. MONITORING DATA FOR NEW WELLS

Well Designation	Date	pH	P(mg/l)	F(mg/l)
Well No. 7	3/82	7.1	1.7	0.48
	5/82	6.6	0.25	0.6
	8/82	6.6	0.95	0.41
	11/82	6.1	1.07	1.3
Well No. 8	3/82	12.7	5.0	1.15
	5/82	11.5	0.04	1.4
	8/82	11.8	0.96	1.2
	11/82	6.8	0.15	0.6
Well No. 9	3/82	7.8	0.32	0.19
	5/82	7.2	0.27	0.20
	8/82	6.9	0.5	0.22
	11/82	6.4	0.59	0.44
Well No. 10	3/82	13.2	2.3	0.34
	5/82	12.4	0.04	0.6
	8/82	12.8	<0.05	0.17
	11/82	11.1	<0.01	0.2
Well No. 11	3/82	8.1	0.32	0.02
	5/82	7.3	0.1	0.27
	8/82	6.8	0.19	0.12
	11/82	6.6	0.01	0.23
Well A	3/82	6.2	116	0.53
	5/89	6.0	146	0.6
	8/82	5.9	130	0.7
	11/82	6.0	159	0.7
Well B	3/82	6.9	40	1.54
	5/82	6.3	34	2.3
	8/82	6.2	16	2.3
	11/82	6.2	72	1.3

(Continued)

TABLE 35. MONITORING DATA FOR NEW WELLS (Continued)

Well Designation	Date	pH	P(mg/l)	F(mg/l)
Well C	3/82	6.6	0.46	0.75
	5/82	6.8	4.2	1.1
	8/82	6.8	0.68	0.3
	11/82	6.8	0.7	0.8
Well D	3/82	6.4	1.6	0.49
	5/82	6.6	1.4	0.47
	8/82	6.5	0.49	0.8
	11/82	6.6	0.7	0.39
Well E	3/82	6.6	1.34	0.56
	5/82	6.7	1.9	0.6
	8/82	6.6	0.47	0.46
	11/82	6.7	0.9	0.45
Well F	3/82	6.6	1.36	0.84
	5/82	6.7	2.0	0.9
	8/82	6.6	0.39	0.6
	11/82	6.7	0.35	2.0
Well G	3/82	7.5	0.16	0.44
	5/82	6.6	1.4	0.6
	8/82	6.6	1.5	3.6
	11/82	6.6	1.1	1.0
Well H	3/82	7.1	0.47	5.75
	5/82	6.6	3.9	5.0
	8/82	6.9	1.5	3.6
	11/82	6.7	1.8	6.4
Well I	3/82	8.2	0.56	1.23
	5/82	6.9	0.7	0.9
	8/82	6.9	0.51	0.47
	11/82	6.9	0.6	0.6

assessment of the stability of the other gypsum stack slopes, and recommendations for safe continued onland gypsum disposal are summarized below. (This information was derived from a recent report resulting from an extensive geotechnical evaluation of the causes of the referenced failure.)

The first two slides occurred in embankments roughly 38 feet high; the third, in an embankment nearly 46 feet high. The first and third occurrences were in the old pond's south side. The second took place on the western side. No major structural damage occurred from any of these slides. There was no loss of acid water. The cause of each failure was judged to be overloading of the clay compounded by the previous deposition of fine-grained, weak gypsum. As a result of these failures, the affected side slopes were reduced to a ratio of approximately 5.5:1 (H:V). The purpose was to avoid loading the slope's uppermost portion where such weight would be an added driving force for failure.

The old pond had been in use (following a 2-1/2 year dormancy period) about 8 months prior to the recent massive failure. At the time of the failure, the decant section (on top of the stack) was filled with roughly 58 million gallons of acid water. The failure began as a break in the southeast corner decant section dike. Water immediately began flowing out of the pond to the south and then to the west. Two parallel zones of cracks, along the slope's longitudinal axis, propagated westward until the entire east-west slope length was included. The major crack zone was between 50 and 60 feet wide and 2,200 feet long. At the slope toe, the ground surface was displaced and the seepage collection dike had risen between 6 and 8 feet.

Because immediately upon seeing the failure's onset, work crews had proceeded to dam off ditches surrounding the facility, all of the acid water was prevented from exiting plant owned property. This was subsequently confirmed by test results of water samples taken during the failure. Spilled acid water was then pumped into the expansion gypsum pond.

Analysis of the massive slope failure has indicated fundamentally different long term performance of gypsum embankments on soft clays than was considered by the initial geotechnical design. (See Table 36 and Figure 22.) The basic difference is the clay's large consolidation settlement (which is time dependent) causing the overlying gypsum to crack in tension and precipitate a slope failure. Based on this failure mechanism, all existing exterior gypsum slopes have the potential for cracking. It was recommended that future pond construction be limited to embankment heights of 35 and 45 feet and side slopes steepness to 4:1 or 6:1 (H:V).

DATA SOURCES USED

1. "Stability Analysis and Detail Design Data, Gypsum and Cooling Ponds," 14 February 1974.

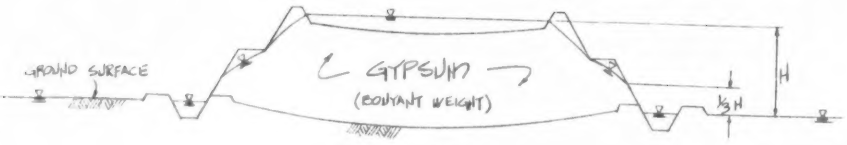
TABLE 36. BEHAVIOR OF INACTIVE GYPSUM EMBANKMENTS

Stage	Considerations	
	Stability Against Slope Failure	Seepage
INITIAL (Figure 5a)		
Just after taking pile out of service. Gypsum embankment is in its final "active" configuration.	Safety factor equal to value determined by latest monitoring.	No pile water recharge except for rainfall.
	- Gypsum "buoyed" by internal water. - Soils strengthened during the past years of controlled loading. - Overall stability (at this stage) is not a problem.	- Seepage exits exterior slopes 1/3 the distance up from the toe. - Amount of seepage will depend on permeability of the gypsum mass. - Quality (pH, P&F content, etc.) also requires checking.
TRANSITION (Figure 5b)		
Exterior gypsum pile surface subsides due to:	Safety factor will initially decrease then increase as the internal water level drops:	Internal water level drops (rate indeterminate).
- Settlement of the subsoil. - Shrinkage of the gypsum as it "dries" (due to falling intra-pile internal water level.) This stage will last roughly 12 to 18 months - possibly longer - depending on permeability of the gypsum mass.	- Gypsum will transition from "buoyant" to "total" weight thereby adding driving force along critical stability arc. - Conversely, the "total weight" gypsum will be stronger (due to additional confining stress) resulting in a safety factor increase.	- Seepage volume will decrease. - Recharge of the internal water level will be by rainfall only. - "Over the side" rainfall runoff will occur - rate and quality must be determined.

(Continued)

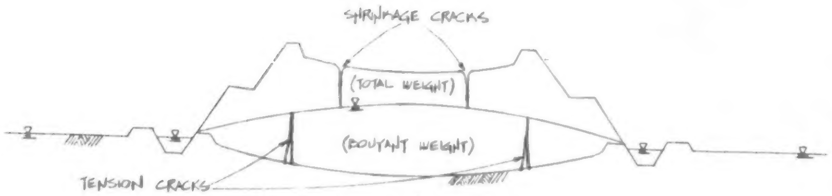
TABLE 36. BEHAVIOR OF INACTIVE GYPSUM EMBANKMENTS (Continued)

Stage	Considerations	
	Stability Against Slope Failure	Seepage
TRANSITION (Figure 5b) (Continued)		
	- "Final" safety factor still requires determination. - "Drying mud puddle" shrinkage cracks will develop. - "Tension" cracks could develop in the gypsum at its interface with the subsoil. - Cracks could affect stability by introducing planes of weakness in the gypsum mass.	
ULTIMATE (Figure 5c)		
Pile exterior surfaces and internal water level essentially constant. Minor deformations may still continue due to slight continued subsoil movements.	Safety factor will gradually increase as subsoils attain "final" consolidation and gain shear strength. - Horizontal hydrostatic pressure against "drying mud puddle" or "tension" crack walls could trigger slope failure. - Long term creep (continued soil deformation under constant stress) may be a problem if transition stage safety factor is too low. More investigation is required to determine the minimum acceptable safety factor.	Reduced seepage will occur. - Recharge of internal water level solely by penetrating rainfall unless pile reopened. - Quality of over the side rainfall runoff needs to be determined. Possibly can be directly discharged, i.e. rainfall runoff may not be contaminated after several rains.


GROUND SURFACE
GYPSUM
(BOUYANT WEIGHT)
H
1/3 H

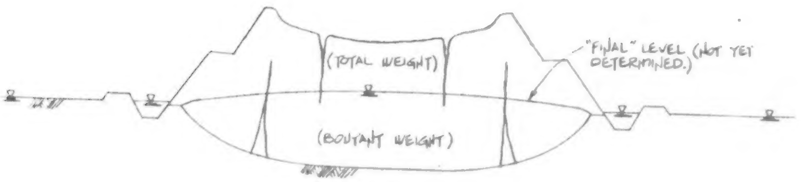
INITIAL STAGE

(a)


SHRINKAGE CRACKS
(TOTAL WEIGHT)
(BOUYANT WEIGHT)
TENSION CRACKS

TRANSITION STAGE

(b)


(TOTAL WEIGHT)
"FINAL" LEVEL (NOT YET DETERMINED.)
(BOUYANT WEIGHT)

ULTIMATE STAGE

(c)

Figure 22. Inactive Gypsum Pond Embankment Stages

2. "Geotechnical Engineering Gypsum Pond Expansion, Phase I," 16 May 1979.

3. "Geotechnical Construction Inspection, Gypsum Pond Expansion," 31 October 1979.

4. "Geotechnical Engineering: Permit Renewal, Gypsum Disposal Ponds," 1 February 1980.

5. "Geotechnical Evaluation, Slope Failure Gypsum Pond Monitoring," 15 August 1983.

6. Miscellaneous Correspondence from State Files.

7. Miscellaneous Company Literature, Ground Water Data.

8. Discussions with the geotechnical consultant's project engineer, November 1983.

9. Discussions with the owner's environmental staff, November 1983.

CASE STUDY NO. 8*

1.0 GENERAL DESCRIPTION AND HISTORICAL BACKGROUND

The two very large EPDM-lined equalization/diversion basins at this chemical production plant discharge their effluent to a regional publicly owned treatment work (POTW) which has been constructed, under joint federal-industry funding, to serve the waste treatment needs of the several major industries in the general area. Before construction of the POTW in 1970's, effluents from these industries were directly discharged to a nearby river which empties into an Atlantic Ocean estuary. The impetus for the construction of the POTW was to lower the pollution load and eliminate uncontrolled discharges to the river and the tidal basin. The POTW first accepted waste in late 1976 and reached full loading by 1977. The industrial plants discharging waste to the POTW are in a relatively flat and somewhat marshy region of this coastal community.

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*This site is actually a "rejection" site and not suitable for a "case study" since the multiplicity of pollution sources preclude design vs performance assessment for the subject SIs. It is, however, included here as a case study because of its history, equalization purpose for the SIs, and circumstances which typify past practices of on-site disposal in many heavily industrialized areas.

There has been considerable and continuous industrial activity in the area since 1900-1910, with a number of companies occupying the site and engaging in a range of production and on-site waste disposal activities. Some of the companies have changed ownership and there have also been changes in the production operations and the commodities produced. As a result of on-site waste disposal by the various occupants, the ground elevation at the site where the subject SIs are located is now about 20 to 30 ft. higher than the original ground in 1900. Fly ash, slag and boiler residue which have been disposed of on site in large quantities account for 15 to 20 feet of the surface build-up.

Past disposal practices reportedly have included percolation of organic wastes into the soil. It is thus impossible to assess the performance of the SIs based on data from monitoring wells which indicate presence of a range of chemicals, some known to be totally absent from the impounded wastes.

The construction of the subject SIs was completed in 1976. The SIs first received waste in November of 1976 and were fully operational and on-line by August 1977. Since the SIs discharge into a POTW, they would be technically exempt from RCRA (and State) hazardous waste regulations. The facility, however, operates under a permit from the regional POTW and the owner/operator is required to submit certain monitoring data to the regional board per terms of their permit.

The current owner/operator of the subject facility is a large operating division of a major corporation conglomorate headquartered in the Northeast U.S. It has occupied the site since late 1920's and is presently manufacturing organic chemicals and synthetic fiber precursors. The wastes discharged to the SIs are from this production as well as the support operations. Much of the data on the original design and supportive studies are in the corporate engineering section of the company and not readily avaialble for use in the present or similar studies.

2.0 BASIS FOR SITE SELECTION

Land availability was the primary reason for locating the SIs on-site. The specific location for the SIs was so chosen as to avoid pumping of the effluent to the POTW. Presently, the effluent flows by gravity to a nearby POTW pumping station.

3.0 DESIGN, CONSTRUCTION AND INSTALLATION FIRMS UTILIZED

With some assistance from the company's corporate engineering group, the owner used his own on-site engineering department to design the SIs. Local contractors were used for site construction and liner installation. The liner installer also supplied the EPDM liner.

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4.0 DESIGN CRITERIA

4.1 Purpose of the Surface Impoundments

The overall purpose of the SIs is to achieve equalization of flow and enable pH adjustment(via acid or base addition) prior to discharge to POTW. The larger pond is a continuous flow basin, whereas the smaller SI is a diversion pond for temporary retention of shock loads (due to process upsets and spills). The retained waste is gradually fed to the discharge line of the large basin (See Figure 23).

4.2 Waste Characteristics

Because of the nature of the operation, the raw wastewater discharge to the SIs is characteristically high in organic nitrogen content and has a widely fluctuating pH. As part of an internal documentation program and under the terms of the discharge permit, the owner carries out extensive wastewater analysis and submits the following data to the POTW on a monthly basis:

pH,TOC and flow	(Continuous Monitoring)
BOD, COD, TSS, NH_3, pH (maximum and minimum, temperature, coliform, total flow and total chloride	(Daily Analysis)

The average wastewater flow to POTW is about 3,000 gpm. Partial analysis of the effluent, highlighting some of the more critical constituents and providing examples of the types of constituents/parameters measured is shown in Table 37. The high chloride concentration in the waste is the result of extensive chlorination of the boiler water to supress biological growth.

4.3 Site Hydrogeology

The river which receives the POTW discharge is also the source of water supply for the industries served by the POTW. The drinking water supply for the town is from a different river in the area. Private wells (300 to 500 ft. deep) serve isolated residences in the outskirts (10 to 15 miles away). Perched water is found about 15 to 30 feet below the surface at the site; this water, however is not used for any domestic and industrial purposes. No hydrogeological studies were conducted to develop basis for the design of the SIs.

4.4 Waste-Liner Compatibility

In arriving at the recommendation to use 50-mil EPDM as liner material, the company's corporate engineering group conducted certain liner-waste compatibility tests. These tests were apparently inadequate in that they failed to identify some of the incompatibility problems which have been

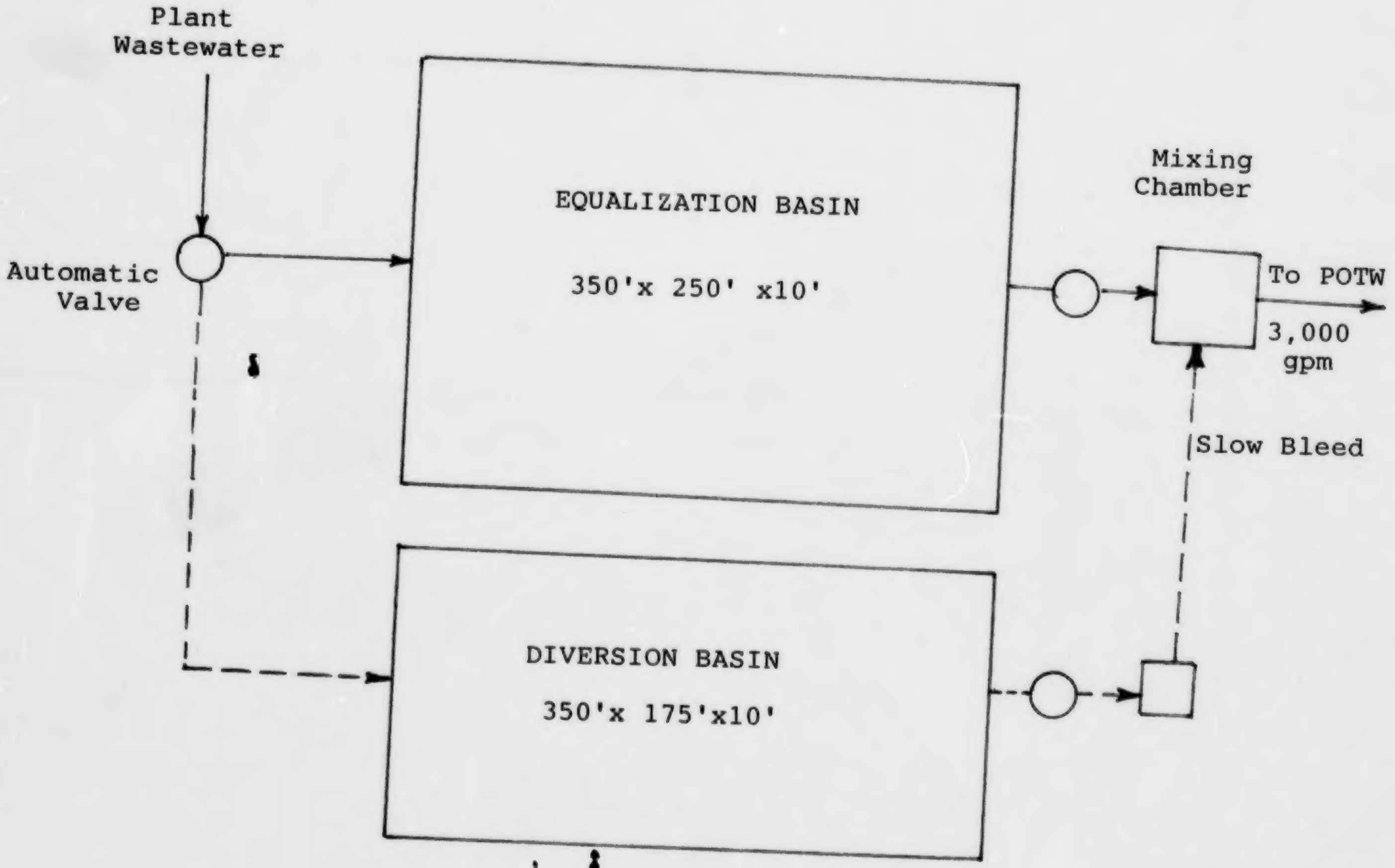
Plant
Wastewater
Automatic
Valve
EQUALIZATION BASIN
350'x 250' x10'
DIVERSION BASIN
350'x 175'x10'
Mixing
Chamber
To POTW
3,000
gpm
Slow Bleed

Figure 23. Dimensions, Arrangement and Flow Pattern for Surface Impoundments

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EPA-287 (Cin.)
(4-76)

TABLE 37. PARTIAL EFFLUENT ANALYSIS (mg/l)

Constituent Parameter	Average	Maximum
pH (Units)	2.4	9.1
Ammonia-N	384	1129
Organic-N	304	330
Nitrate-N	11.27	51
Phenol	1.9	4.9
Phenolics	3.09	10.8
Acetic acid	14.2	101
Acetohydroxamic Acid	<0.01	<0.03
BOD_5	403	1680
COD	638	1371

experienced (see Section 7.1). The records of any such tests and their results, however, are not readily available now.

4.5 Soil Permeability

As with the waste-liner compatibility tests, some soil permeability tests preceeded the SI design. The records for such tests, however, are at the company's corporate headquarters and are not readily available. As indicated in Section 1.0, however, the soil at the site contains large amounts of previously deposited wastes (fly ash/slag) in a clayey-sand matrix. The soil would thus be expected to be very permeable.

4.6 Regulatory and Permit Requirements

At the time that the SIs were designed and constructed, no specific regulations governed the design and construction of such facilities.

4.7 Cost Considerations

The selection of the EPDM as the liner material was apparently based on its relatively low cost (as well as its ready availability and ease of installation). Insofar as the selection of the construction and installation contractors was based on bids received, cost must have been a consideration in selecting contractors.

5.0 DESCRIPTION OF DESIGN AND DESIGN SPECIFICATIONS

5.1 Dimensions and Configurations

When full, the water surface area of the continuous flow SI and the diversion SI is 350 feet by 250 feet, and 350 feet by 175 feet, respectively. The full water depth is then about 10 feet (with about an additional 1 foot of freeboard). Only about 4 feet of the depth is below the ground surface. The sides are at about 30° inclination, providing for total impounded working volumes of 4.5 and 3.5 million gallons, respectively.

5.2 Liner

The specifications for the installation of the 50-mil EPDM is not readily available. There was no protective soil cover for the liner.

5.3 Foundation Preparation, Leak Detection System and Backfilling

Specifications for excavation, foundation preparation, berm construction, and backfilling are not readily available. The EPDM liner was placed on about 2 feet of compacted clay. The seepage collection system design called for the use of 4-in. perforated polythylene pipes with cheese cloth wrapped around them. Data on other design specifications are not available.

5.4 Inlet/Outlet and Other Structures and Provisions

The schematics of the inlet/outlet arrangements are shown in Figure 23. Engineering data on design and construction are not readily available.

The entire plant area, which includes the two SIs, is fenced off and is under TV camera and guard surveillance.

5.5 Observation Wells and Monitoring Systems

There are a total of 10 monitoring wells: 3 downgradient, 2 upgradient and 5 in the general vicinity. The general vicinity wells were installed in 1981-82 per recommendation of an outside consultant because of the inconclusiveness of the data from upgradient wells. The monitoring wells are about 30 ft. deep.

5.6 Quality Control/Quality Assurance Specifications

The QA/QC program called for in the design and construction specifications are not known

6.0 DEVIATIONS FROM DESIGN PROBLEMS ENCOUNTERED DURING CONSTRUCTION, AND COSTS

6.1 Deviation from Design

Some major deviations from design which had occurred during construction were uncovered when the system was inspected in 1981. The rationale for deviations, however, is not known and was not well documented during construction. These deviations relate to seam construction and the seepage collection system. The inspection of the liner indicated that the seaming deviated from the recommended specifications in that the amount of sheet overlaps in certain areas was significantly less than the design recommendation. Also, the seepage collecton design had called for the use of 4in. perforated polyethylene pipe with cheese cloth wrapped around them; in actual construction, however, clay tiles with 1/4-in. holes on 3/8-in. centers had been used instead.

6.2 Problems Encountered During Construction

No information is available on problems (if any) encountered during construction.

6.3 Level of QA/QC Competency

When the liner was inspected in 1981 to determine the causes of its failure, there was some very strong evidence that there had been a lack of adequate QA/QC during construction and that some major deviations from design specifications had gone undetected. The responsibility for construction verification, documentation and acceptance record keeping was with the project engineer assigned to the job by owner; this individual is no longer with the company.

6.4 Cost Data

Although no data is readily available on the original cost of the completed SIs, the estimated cost for replacing the current failed liners is in the $2 million to $3 million range.

7.0 PERFORMANCE DATA AND OPERATING EXPERIENCE

7.1 Liner Performance

The failure of the liner is manifested as extensive swelling and permeation of the liner and separation of seams. In the presence of the particular organics encountered in the waste, EPDM apparently is subject to swelling and permeation at the air/water interface. This problem was not detected during the liner-waste compatibility tests which proceeded the liner material selection.

Two years ago when the owner drained the SIs and inspected the liner, seam separation was noted in a number of areas. A nationally recognized authority on liner installation as well as a local consultant who inspected the liner were in concurrence that the seam separation resulted from a deterioration of the glue used as well as the inadequate overlapping of the sheets.

7.2 Seepage Collection System Performance

Inspection of the seepage collection system has revealed that the majority of the clay tiles used in the drainage system are clogged. This has been attributed to (a) failure to provide a filter protection mechanism, and (b) deviation from the original design which called for use of perforated PE pipes instead of the clay tile actually used.

7.3 Ground Water Monitoring Data

The data from the ground water system have generally been inconclusive due to erratic nature of the ground water movement and tidal basin characteristics of the area. Also, because the soil matrix is composed largely of previously deposited wastes, any observed contamination of the ground water may bear no relations to the performance of the SIs.

8.0 FUTURE PLANS

The owner has hired a nationally-recognized authority on synthetic liners to provide assistance in selecting a new material for relining the site. Learning from past errors, the owner intends to assign a very competent and thorough engineer to the job to make sure that the new construction and liner installation would strictly conform to design specifications. Because the owner has to justify significant construction expenses which would be required, he has to demonstrate to the satisfaction of his management at the headquarters that the new facility will perform satisfactorily for at least 10 to 15 years. To this end, the owner plans to do the best possible job, including undertaking extensive supportive studies and thorough construction inspection and verification.

SOURCES OF DATA USED

1. Discussions with plant's Environmental Control Supervisor, November 10, 1983.

CASE STUDY NO. 9

1.0 GENERAL DESCRIPTION AND HISTORICAL BACKGROUND

This case study deals with an FML-lined uranium tailings pond built to handle wastes from a uranium mining and milling operation located in a remote area of a northwestern plain state. The climate is dry and sunny with cold winters and warm summers. Very strong winds are very common in the area. The site of the uranium facility is 15 miles from the nearest residence which is used only part of the year. There are no permanent residences within a 20 mile radius of the site(1).

Preliminary engineering studies were begun in 1972. After several modifications and revisions, the final design for the tailings pond was a rectangular below ground basin with four cells of 60 to 65 acres each, only the first of which has been built(2). This first cell was completed in August, 1980 and used until recently when the entire mining and milling operation was closed down for a period of five years(3).

2.0 BASIS FOR SITE SELECTION

The uranium tailings pond was probably built adjacent to the mill primarily to facilitate waste disposal. Other criteria used for site selection (if any) are not known. Figure 24 shows the plot plan of the mine, mill and tailings pond(2).

3.0 DESIGN, CONSTRUCTION AND INSTALLATION FIRMS USED

A private consulting firm was engaged by the owner/operator in 1972 to investigate the site and design the tailings retention facility. A final report on the design of the basin was submitted to the owner/operator in 1977(2). After review of this design by NRC, state agencies and the public, the owner/operator proposed a modified design that essentially changed the facility from above ground to below ground. This modified design was reviewed by a different consulting firm(4,5) which made a few recommendations but did not substantially change the original design. The first cell of the tailings pond was constructed by a construction contractor and the owner/ operator in 1980. The synthetic liner was installed by a commercial installer(6).

4.0 DESIGN CRITERIA

4.1 Purpose

The purpose of the surface impoundment cell is storage and ultimate disposal of mill tailings waste and containment of water for mill operations. After the design capacity for tailings waste has been reached, the basin will be used for water storage and controlled evaporation before it is abandoned and covered(6).

4.2 Waste Characteristics

The wastes received by the pond are produced by the milling of uranium ores into uranium oxide or yellowcake. These wastes or tailings are in the form of a slurry of about 50 percent solids (primarily fine sand) by weight(2). The aqueous phase contains 0.5 percent by weight sulfuric acid and 0.25 percent by weight organics (kerosene) and has a pH of 1.8 to 2.5(7).

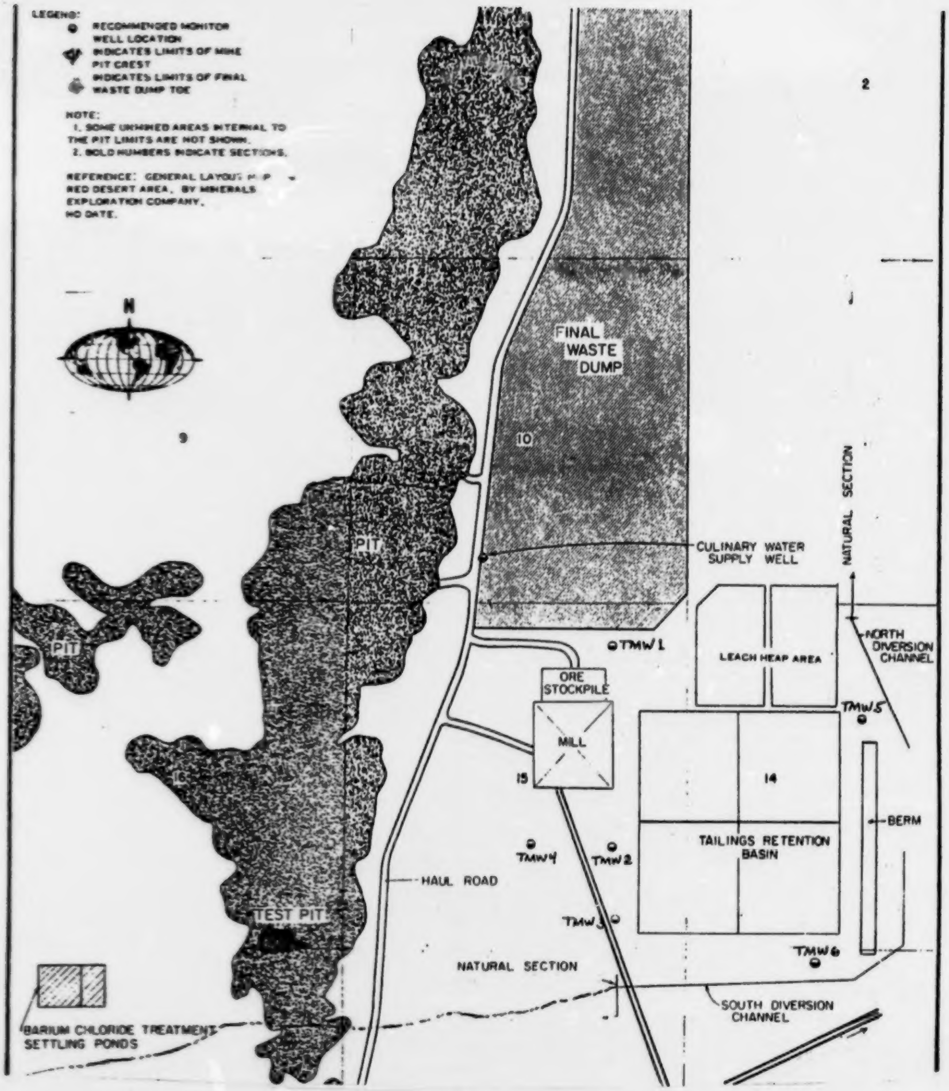
LEGEND:
RECOMMENDED MONITOR WELL LOCATION
INDICATES LIMITS OF MINE PIT CREST
INDICATES LIMITS OF FINAL WASTE DUMP TOE
NOTE:
1. SOME UNMINED AREAS INTERNAL TO THE PIT LIMITS ARE NOT SHOWN.
2. BOLD NUMBERS INDICATE SECTIONS.
REFERENCE: GENERAL LAYOUT MAP RED DESERT AREA, BY MINERALS EXPLORATION COMPANY, NO DATE.
N
2
9
10
FINAL WASTE DUMP
PIT
PIT
CULINARY WATER SUPPLY WELL
NATURAL SECTION
TMW1
ORE STOCKPILE
LEACH HEAP AREA
NORTH DIVERSION CHANNEL
TMW5
MILL
15
14
BERM
TAILINGS RETENTION BASIN
TMW4
TMW2
HAUL ROAD
TMW3
TEST PIT
TMW6
NATURAL SECTION
SOUTH DIVERSION CHANNEL
BARIUM CHLORIDE TREATMENT SETTLING PONDS

Figure 24. Plot Plan of Proposed Mine and Mill Facility

The temperature of the waste at discharge is 50 to 80°F. Uranium mill tailings also contain radioactive materials in excess of NRC allowable discharge limits. The most significant of these radioactive elements is radium - 226 which has a half-life of about 1,600-years(8).

4.3 Service Life

The entire tailings basin was designed to be constructed and used for waste and water storage over a period of about 15 years(4). Each of the four cells will have a service life of approximately four years for tailings accumulation and a similar period for controlled water evaporation.

4.4 Site Hydrogeology

The hydrogeology of the site was investigated in 1976 prior to development of the construction design for the facility. Hydrogeologic information is contained in the environmental report, the design engineering report and a report of ground water conditions(1,2,9). A brief review of the most pertinent data in these reports which provided the basis for facility design and construction follow.

Topography and Climate

The site for the mine, mill and tailings pond is a semi-desert area in a large watershed basin surrounded by mountains. The climate is dry and cold. Temperatures range from about 8 to 80°F. Rainfall is only about 6 in./yr; the lake evaporation rate is 42 in./yr. The terrain is nearly flat. Vegetation consists of sparse grass and brush. The site is isolated, having no permanent residences within 20 miles and only one part-time residence 15 miles away(1).

Geology and Seismicity

The site is underlain with interbedded mudstones, siltstones and sandstones covered by a thin layer of sandy and silty alluvium. Under the site the bedding is nearly horizontal. The sandstones consist primarily of lenses or channels. The soils are 4 to 13 feet thick and generally dense with field permeabilities on the order of 10 to 20 ft/yr (1×10^{-5} to 2×10^{-5} cm/sec).

The general area of the site is considered a relatively inactive region in terms of seismic activity. Preliminary assessment data indicate no known active faults within 50 miles of the site. Potentially active faults lie within 30 miles to the northeast and northwest. Several small earthquakes have occurred in the vicinity of the site. However, these events cannot be related to known major faults or geologic structures. Based on the above analysis, the horizontal acceleration for the site area that has a 90 percent probability of not being exceeded in 50 years has been estimated at less than 0.04g. The small local earthquakes and a larger earthquake far away would produce ground motion less than 0.04g and so this value was used for design purposes(2). A peak acceleration of 0.08g for the 1000 year earthquake (maximum probable earthquake) was used without verification but appeared to be a reasonable value(10).

Hydrology

A ground water study was performed after the completion of the design report(9). This study dealt with the following:

- location of the water table
- fluctuations in the static water level
- presence of any perched ground water
- rise in the water table due to runoff from intense storms.

In general the area around the site is so well isolated that changes in local hydrological conditions are due primarily to natural phenomena (e.g., rainstorms, normal ground water flow, seepage) rather than human activities (e.g., farming, mining, domestic consumption). There is no evidence of change in static water levels within the 15 years preceding the mining operations. A 15-year mining activity at the site is expected to reduce levels 74 to 97 feet. After discontinuation of heavy water withdrawal, the water table is expected to return to normal levels in about 15 years(9).

The water table was located by the seven wells nearest the site to be about 72 to 150 feet below the ground surface. Several test wells and 14 observation wells drilled in the general vicinity of the site revealed no perched ground water above the water tables.

The major hydrological concern to the design and construction of the tailings pond was the effect of the maximum probable storm generating a flood. Recharge to the water table due to precipitation in such a semi-arid desert is negligible. Recharge is due primarily to runoff. The maximum probable 6 hr storm (PMP, probable maximum precipitation) would deposit 15 in. of rain, 14.5 inches of which would become surface runoff. Considering the drainage area above the site with an area of 13.7 square miles, this storm would produce a flood of 13 hr duration and a peak discharge of 18,000 cfs (PMF, probable maximum flood). Hypothetically, if all of this water were to percolate at one point to the water table, it would raise the water level 9 feet(9).

Stream and Runoff Diversion

A draw cuts through the southeast corner of the tailings disposal area. Flow in this stream channel is intermittent and infrequent. A diversion ditch and a berm on the east side of the pond have been constructed to divert water flowing through this area around the cell embankments and away from the toe of the dam. Adequacy of the diversion ditches and the berm on the east side of the pond to protect the basin embankments from the erosion effects of the probable maximum flood (PMF) described above has been analyzed by NRC(11).

The design of the stream diversion system was based upon a 2.5 in. rainfall of 6 hr duration, the 100 yr storm. The 6 hr, 100 yr precipitation event for this area had been determined by two investigators to be 1.7 in. and 2.5 in. The more conservative value of 2.5 in. was chosen for design purposes(2). The PMF was not used as a design criterion. The rainfall for a PMP generating a PMF would be 15 in. as previously stated. Evaluation of the diversion system by the NRC concluded that the channels will safely pass flow due to the 100 yr precipitation event but not the occurrence of the PMF which in turn would cause failure of the retention system(11).

Although the diversion system would not withstand the effects of the PMF, the retention facility design was determined to have met NRC requirements because any release of tailings due to dam failure would be contained and controlled within the boundaries of the owner/operator's property. This situation was deemed sufficient to meet NRC guidelines restricting release of contaminants at the site boundary because the area of the site was in fact a closed hydrological system and would justify use of less conservative flooding criteria (less than PMF)(11). In addition, NRC concluded that the additional fill placed in the basin upon abandonment would protect the embankments from the PMF even though the diversion channels would overflow.

In 1978, due to state recommendations, the safety berm on the east side of the basin was extended the entire length of the south side channel(12). Figure 25 shows the final configuration of the berm and diversion ditches around the tailings pond.

4.5 Waste-Liner Compatibility Considerations

Based on the information available, the selection of the liner material appears to have been based primarily on the compatibility data reported in the literature or supplied by the manufacturers and no waste-liner compatibility tests were conducted by the owner or the design engineering firm. Published data on Hypalon liners indicated that a 50 percent sulfuric acid solution at 250°F would have little or no effect on Hypalon(12). The same data also reported a minor to moderate effect of kerosene on Hypalon and an incompatibility with PVC.

4.6 Soil Permeability and Pollutant Attenuation Considerations

Based on the information available, it appears that no tests to determine soil permeability to the particular waste or capacity of soil to attenuate pollutant migration preceded the actual surface impoundment design. The use of plastic liner apparently preempted concerns for ability of the soil to contain waste. Extensive soil mechanics testing, however, were conducted in connection with dike design to eliminate potential for catastrophic failures. These tests, which were required by NRC prior to construction(14), included:

- penetration tests to document the density of the upper 10 feet of embankment foundation material,

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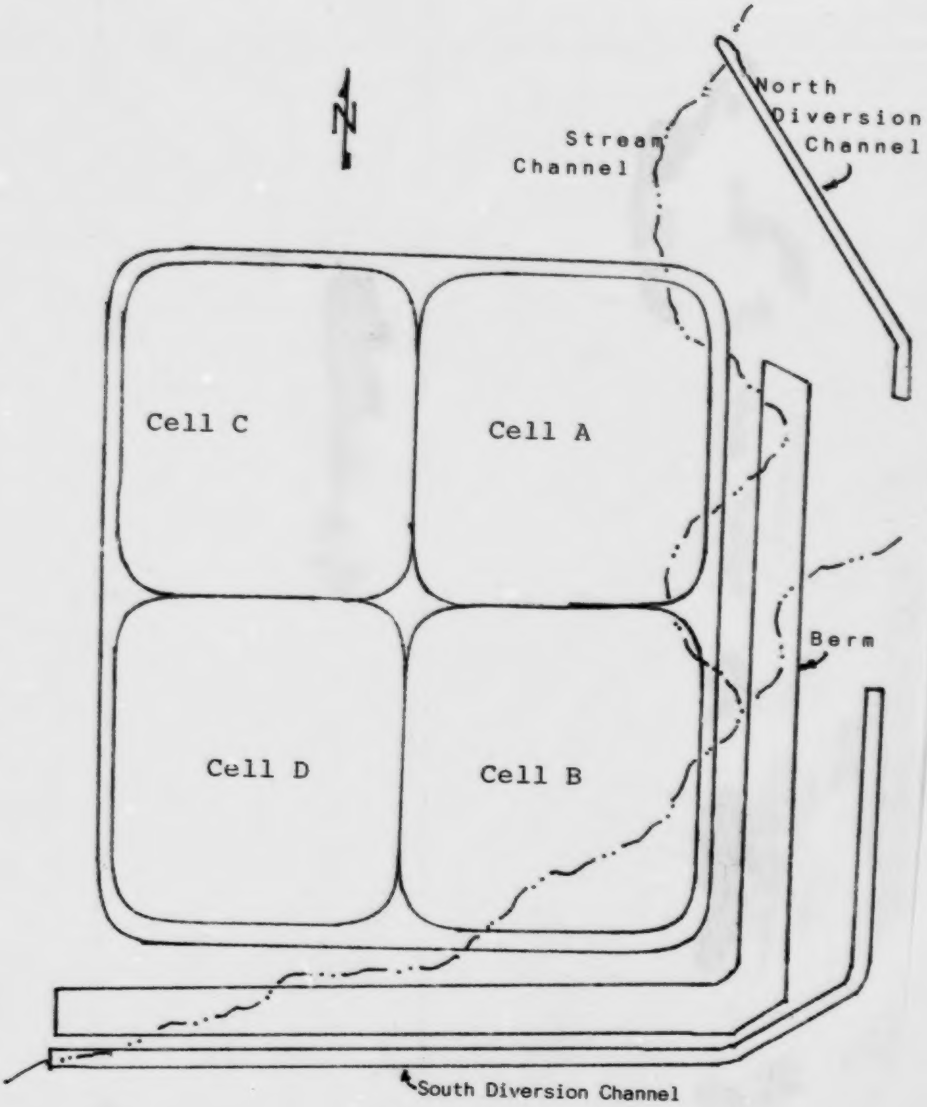
N
North Diversion Channel
Stream Channel
Cell C
Cell A
Berm
Cell D
Cell B
South Diversion Channel

Figure 25. Stream Diversion System(2,12)

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EPA-287 (Cin.)
(9-76)

- testing, removal or compaction of loose materials with liquefaction potential during the 1000 year earthquake.

4.7 Regulatory and Permit Requirements

This hazardous waste site is regulated locally by the state department of environmental quality. Since the waste is generated at a uranium mining and milling facility and contains radioactive materials, it is also regulated and licensed by the NRC. The primary concern of NRC is the containment of the waste not only for the service life of the facility but also for several generations after mill operations cease due to the long half-lives of the radioactive constituents of the waste(8).

Minimizing exposures and releases of radioactive materials to unrestricted areas requires the stability of the facility under all conditions for extended periods of time. To this end NRC has developed extensive guidelines for design and construction of facilities handling radioactive materials. NRC carefully reviews proposed designs for waste disposal sites as part of its licensing and permit approval process and in this connection the subject facility was no exception.

The NRC goals and guidelines which provided the basis for the approval of the subject facility included the following general design objectives:

- stability of the facility for the expected life of radioactive constituents,
- provision of required storage,
- control of seepage to prevent contamination of land, waterways and groundwater,
- prevention of wind and water erosion.

In order to meet the above criteria, NRC recommends that the following analyses be performed:

- on site conditions: climate, hydrology, geology, and seismology;
- on foundation and embankment materials: classification, shear strength, consolidation, permeability, sedimentation, compaction, piping and cracking susceptibility and wind and water erosion characteristics;
- chemical qualities of tailings and slurry.

To aid in the design, construction and maintenance of licensed facilities, NRC has issued Regulatory Guides that give advice to applicants. The guide for embankment retention systems covers three main topics:

- design analysis including hydrology and stability analyses,

- construction methods, especially multiple stage construction,
- inspection and maintenance programs.

4.8 Cost

No cost data were available.

5.0 DESCRIPTION OF DESIGN AND DESIGN SPECIFICATIONS

5.1 Dimensions and Configurations

The original design was that of an above ground unlined rectangular impoundment that was later changed to a lined facility, then a below ground more heavily lined pond and finally the four-cell configuration shown in Figure 25(2,15). When fully constructed, the entire four-cell facility will cover 255 acres, each cell occupying 62 to 64 acres. The sequence of cell construction was also changed several times(16). The C cell was constructed and used prior to a plant shut-down for the next 5 years. It was 3,100 by 3,500 ft in plan dimensions which, when filled to within 10 ft of the ground surface, would hold 466 million gallons of tailing waste(5).

The depth of excavation to the center in each cell was to be about 50 ft below the ground surface and 22 to 23 ft above the water table(5). The side embankments were to be about 40 ft in height and constructed with an inner vertical core of compacted soils keyed to impermeable material with a 15-ft bench at the ground surface and above ground embankment walls(17,18). Figure 26 shows a cross section of the pond sides.

5.2 Liner

The liner for cell C is 30-mil PVC on the bottom of the basin and 30-mil polyester reinforced Hypalon on the sides(19). The bond between the PVC and Hypalon was to be plant fabricated using a dielectric or heat weld. This seam was to be placed in a fold near the toe of the slope and covered with soil. The side liner was to be installed in two segments meeting at the bench at the ground surface (see Figure 26)(20). A soil cover was recommended initially in 1978 by the consulting engineers. Later, the liner manufacturer/fabricator and installation contractor recommended against its use. The engineering firm concurred with this recommendation and the soil cover was omitted from the final design, except at the top of the dike, the bench and liner seam and construction access ramps(20).

The rationale for the decision against the use of soil cover apparently stemmed from the concerns that: (a) any soil cover would readily erode away given the anticipated strong winds and wave actions, (b) potential for damage to the liner by equipment used for placing cover, and (c) inaccessibility of the liner for inspection and maintenance. The concern for erosion of the soil cover appears to have been a correct one since field observations indicated that the soil cover placed at the top of dike, the bench and liner seam and construction access ramps readily eroded by the strong winds and waves experienced.

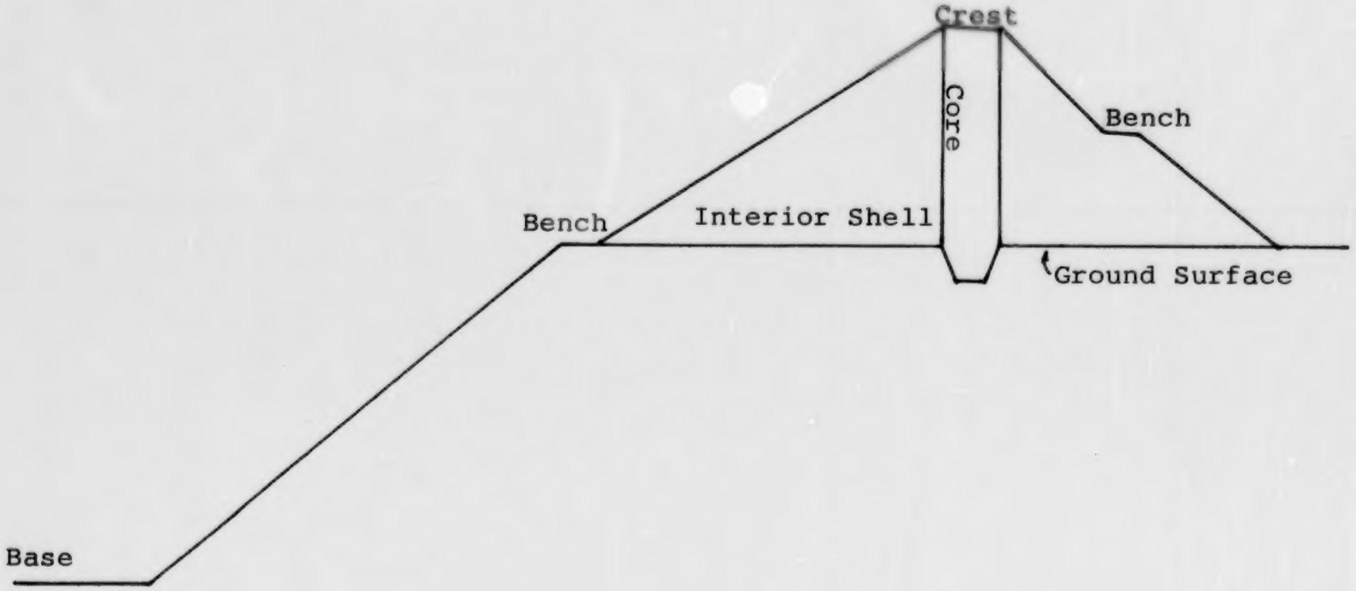
Crest
Core
Bench
Bench
Interior Shell
Ground Surface
Base

Figure 26. Cross Section of Embankment (18)

5.3 Foundation Preparation, Leak Detection System and Backfilling

Following excavation the pond bottom was leveled, scarified, proof-rolled and compacted to create a smooth surface for the liner. The under-drain system was installed prior to site preparation and consisted of five 2-in. perforated plastic pipes running north to south spaced 200 ft apart on the bottom of the basin. A 4-in. collection pipe runs along the southern toe and a 6-in. pipe runs from the bottom of the pond to a manhole system on the southern embankment. The pipes were placed in compacted gravel and covered with compacted sand(18).

Backfilling was done by the owner/operator as well as contracted to a construction company. Three classes of fill material were processed and placed in the embankment exterior shell, core and inner shell (see Figure 26)(17).

5.4 Inlet/Outlet and Other Structures and Provisions

The tailings are piped under pressure to the pond as a slurry. Twelve discharge points around the periphery of the basin are used to facilitate even distribution of the tailings by means of a movable discharge pipe(20).

5.5 Observation Wells and Monitoring System

The ground water monitoring system consists of six monitoring wells plus a drinking water supply well (see Figure 24). These wells were sampled at least quarterly for various chemical and physical parameters. The first four sampling reports were to constitute baseline data and give an indication of ground water quality prior to construction of the disposal facility. The contents of the tailings pond was also monitored regularly for the same parameters as the ground water. These parameters are listed in Table 38.

5.6 Quality Assurance and Quality Control Specifications

The quality control staff for the construction of the tailings pond included(21):

- A Soils Engineer/Inspector, who is an outside consultant;
- the Chief Engineer, who is responsible for the construction of the dam and receives recommendations and instruction from the consulting Soils Engineer/Inspector;
- the Construction Supervisor;
- the Safety and Environmental Administrator, who is in charge of employee safety and is also compliance officer for the dam construction;
- NRC inspector(s);
- an Army Corps of Engineers inspector, who is a consultant to NRC.

TYPING GUIDE SHEET

TABLE 38. PHYSICAL AND CHEMICAL PARAMETERS MEASURED FOR THE GROUNDWATER AND TAILINGS POND(18)

Physical Measurements

- temperature
- dissolved oxygen
- pH
- conductivity
- dissolved solids
- suspended solids
- alkalinity
- hardness

Chemical Measurements

- sulfate
- COD
- redox potential
- total iron
- dissolved iron

Chemical Species

- lead
- zinc
- manganese
- sodium
- silica
- nickel
- chromium
- chloride
- calcium
- nitrate
- arsenic
- boron
- phosphate
- fluoride
- aluminum
- mercury
- selenium
- potassium
- copper
- cadmium
- vanadium
- molybdenum
- magnesium
- carbonate
- bicarbonate

Isotopes

U - natural
Ra - 226
Th - 120
Pb - 210
Po - 210

EPA-287 (Cin.)
(4-76)

Inspections were made throughout the construction period (February 1979 to August 1980) by representatives of the soils engineering consultant, NRC and Army Corps of Engineers (CoE) as a joint effort, and the liner manufacturer(17,22,23). Inspection reports were available for the consultant and the CoE.

The installation of the liner, development of specifications for such installation (including specifications for QA/QC) and verification of the installation work to ensure adherence to specifications were apparently the sole responsibility of the owner and did not involve participation of NRC or its consultants (however, NRC does require daily inspections of the liner). Based on the information available, it appears that liner design and installation did not receive much attention as they were viewed as insignificant elements in the overall system performance.

6.0 DEVIATIONS FROM DESIGN, PROBLEMS ENCOUNTERED DURING CONSTRUCTION AND COSTS

6.1 Deviations from Design

No deviations from design specifications were noted in the construction inspection reports available. Although a representative of the liner manufacturer was reported to have inspected the liner installation, no report of inspection was available(17). Investigations of liner failure (see Section 7.0) revealed a deviation from design installation of the liner. The seam connecting portions of the Hypalon liner material was to have been buried in a ditch close to the junction of the pond bottom and side slopes on flat ground(24). It was installed, however, higher up on the side slopes and above ground (i.e., not in a ditch). This change in liner installation was made because the excavation contractor was behind schedule and time to completion was running out(24). After excavation of the pit had begun but before installation of the liner, a change was made in the liner specifications by omission of the soil cover (see Section 5.2).

6.2 Problems Encountered During Construction

Construction was begun in February 1979 and halted over the winter of 1979 to 1980. The final stage began in April 1980. The liner was installed in July and August 1980. No major problems were reported in inspection reports except for the delays due to weather(17,22,23).

6.3 Level of QA/QC Inspection Competency

The inspections of construction work, compaction testing and earthwork are well documented by the outside consultants. There was no record available of the owner/operator inspections or the work of the liner manufacturer and installer.

6.4 Cost Data

No cost data were available for this facility. It was noted, however, that the cost of PVC is less than half of reinforced Hypalon and so PVC was installed on the pond bottom. Hypalon was required on the side slopes due to higher tensile stresses on the slopes and the higher tensile strength of Hypalon versus PVC(24).

7.0 PERFORMANCE DATA AND OPERATING EXPERIENCE

7.1 Liner Performance

Documented Instances of Liner Failure

Following installation in July and August 1980, there have been four instances of documented failure of the liner in the tailings pond(15):

- 4 months after installation a Hypalon-to-Hypalon seam separated for a distance of 300 ft;
- during a subsequent site visit to inspect the repair to the seam separation, some 50 small puncture patches were noted;
- in October, 1981, a 6-in. hole was worn through the liner by a leak in a discharge pipe;
- most recently in June 1983, a series of punctures and tears were caused by floating debris and wave action.

Causes of Failure and Corrective Measures Employed

According to NRC staff, the first two failures were due to a weak bond and careless inspection, respectively. The last two failures were the result of poor maintenance of the pond system(15). The liner was properly repaired in each instance. Liner repair, without some type of non-erosive shoreline protection, was deemed by NRC staff to be a temporary solution to a recurring problem. A more permanent solution was recommended in providing some type of shoreline protection for the liner, such as a concrete filled mat or a soil cover as proposed previously (see Section 5.2). No action was taken at this time because the entire facility is to be shut down for 5 years.

Just 4 months after installation, at the end of December 1980, the 300-ft seam separation was discovered extending from the northeast corner of the pond. The liner installation contractors were called in to repair the liner since it was still under warranty. They determined that the cause of the failure was a weak chemical weld made under improper temperature conditions. When mechanical stress, especially wave action, was applied to this weak seal, it separated(25). In January, 1981, NRC staff and an NRC advisor made a site visit to this facility to determine more fully the cause of the failure. They discovered that the liner had not been properly installed(24). Due to construction delays the Hypalon to Hypalon seam was not placed in a ditch near the pond bottom but was located at the soil surface on the slope of the embankment. The seam area that separated was weak and could be pulled apart by hand where it had not already failed. This weakness was perhaps due to the low ambient temperature at the time of sealing. The presence of the weak seam on the slope at or slightly below the water level allowed water to move into the seam and break it by freezing, thawing and wind action. If the seam had been located near the bottom of the pond, it probably would not have failed(24).

In addition to its placement on the slope, the Hypalon seam was installed with the lower piece of Hypalon attached to the PVC lapped over the top instead of underneath the upper piece of Hypalon. This positioning of the liner pieces allowed water to enter and break the seam by freezing and thawing. If the Hypalon on the slope had been lapped over the top and not beneath the Hypalon connected to the PVC, the weak seam probably would not have failed because the water would not have been able to enter as readily and produce the freezing and thawing stresses to the seam(24). The position of the weak seam at or slightly below the water level also contributed to the break in localizing the freezing and thawing and wave action stresses at the seam itself.

Repair of the liner involved installation of a Hypalon strip between the upper and lower seamed pieces. The new seams were double overlapped and sandwiched between two 1 x 4 inch cedar boards nailed together. Sand bags were placed along the toe of the slope on top of the Hypalon splice to prevent wind from lifting the liner and damaging the repair seams(24). The repair seams should remain stable, though, as long as they are covered with tailings waste(24).

At the time of failure the pond contained about 23 million gallons of fresh water, 3,000 tons of tailings, 180,000 gallons of acidified tailings effluent and about 10.5 million gallons of water used to put out a fire in the mill(18). Total fluids were about 33.5 million gallons containing roughly 4.5 ppm U_3O_8. Leakage from the pond is estimated to have been between 18,000 and 70,000 gallons. Due to the permeability of the underlying strata, the tailings liquid did not move laterally beneath the liner but downward and so was not detected by the underdrain system which was located inward from the leak(18). The design of the leak detection system was later determined by NRC staff to be inadequate to detect any leak unless it occurred directly over a collector pipe(26).

During the January NRC site visit additional damage to the liner was observed in the occurrence of about 50 small holes that had been patched since the liner was installed(24). The holes were apparently caused by one or more of the following:

- dropping of sharp objects by work crews during installation;
- small rocks and hard dirt clods under the liner;
- an uneven surface of ridges and depressions beneath the liner perhaps due to vehicle traffic during installation or runoff prior to liner installation.

In October 1981, a break at a bend in a tailings discharge pipe allowed tailings slurry to enter the pond 15 ft upstream of the discharge point. Turbulent flow of tailings slurry at the bend caused erosion of a 6-in. hole in the liner. From 5 to 10 cubic yards of tailings (about 1,300 gallons of liquid) were forced under the liner(27,28).

The leak and subsequent build up of solids under the liner occurred during the 24 hour period since the last inspection of the liner. The leak detection failed to indicate the presence of the leak(28). Repair to the liner involved splicing the liner back together with a patch 4 to 5 ft wide and 20 ft long. The size of the patch was determined by the hole cut in the liner to remove the solids forced underneath by wave action. In the liner repair the downhill sheet was anchored in a trench 12 to 18 in. deep. The new liner material was bonded between the uphill and downhill sheets(28).

To prevent further occurrences of this type a thicker walled discharge line was installed. The line was also raised on cribs or crossed supports. Raising the line decreased the sharpness of the bend in the pipe and also made visual inspection of the discharge line much easier(28).

The most recent damage to the pond liner was reported in June 1983. This damage consisted of a series of punctures and tears ranging in size from pinholes to 10- to 12-in. rips(29,30). Cause of the holes appears to be floating debris and wave action. These stresses have formed a ridge of rocky material under the liner on the slope of the pond. These protuberances and the debris and water movement have caused abrasive holes in the liner(29). Some of the floating debris is due to destruction of the support for the discharge line during a severe winter storm.

Long Term Corrective Measures

Due to the extent of the recent damage to the liner (about one hole per each 100 ft of shoreline), the owner/operator arranged with their engineering consultants to assess the present liner system and make recommendations about its repair and prevention of future problems(30). The consultants essentially agreed with the above assessment of the present liner damage by the owner/operator. Immediate corrective action recommended involved patch repair of the holes and continuous removal of debris from the pond area. Long term suggested solutions include:

- cut the liner in several places to expose the ridge built up under the liner, remove the rocks and smooth out the ground surface, replace and patch the liner;
- increase the number of sand filled Hypalon tubes placed along the upper slopes of the pond to prevent movement of the material under the liner;
- when the liner is exposed for repair, bond a heavy nonwoven geotextile underliner to the Hypalon to protect it against abrasion;

- use a floating breakwater to decrease wave action (this system has never been used in a lined pond and would be considered experimental);

- install mats of heavy material placed along the shoreline and anchored to the top and bottom of the pond (these heavy mats would require careful placement to avoid damage to the liner; if large fluctuations in water level are anticipated, large areas would have to be covered by the mats);

- systematic discharge of tailings along the windward (NE) shoreline would allow build up of a beach area to act as a buffer between the ponded water and slope to protect the slope from debris and wave action.

Evaluation of the consultant's recommendations resulted in the decision by the owner/operator to patch existing holes, keep the pond free of floating debris and also initiate some long-term solutions(31). The long-term measures were to cut the liner and smooth out the ridge build up under the liner, adding more sand-filled tubes to the upper slopes and directing tailings discharge to the windward (NE) shore to promote development of a protective beach. Some negotiation regarding shoreline protection may be necessary once the facility is in operation again as none of these long-term measures were those suggested by NRC staff(15).

7.2 Monitoring Data

An evaluation of monitoring data for this facility was made recently by NRC staff(32). Samples are routinely taken of the 6 tailings groundwater monitoring wells, the potable supply well and 2 wells adjacent to the mine pit. Laboratory tests were performed for 5 isotopes and over 30 physical and chemical parametes (see Table 38). Analysis of the data for the first and second quarters of 1983 indicated no apparent trends or large increases in constituents.

REFERENCES AND DATA SOURCES

1. Environmental Report, 1976.

2. Revised Final Report On Design of Tailings Retention Basin, October, 1977.

3. Review of First and Second Quarter, 1983 Environmental Monitoring Data, NRC, November, 1983.

4. Assessment of Liner Requirements, Uranium Mill Tailings Pond, July, 1978.

5. Subsurface Tailings Disposal, June, 1978.

6. Recommended Changes, Uranium Tailings Pond Liner System, July, 1979.

TYPING GUIDE SHEET

7. Warranty for Pond/Pit Liners, March, 1979.

8. NRC Regulatory Guide 3.11, December, 1977.

9. Groundwater Conditions in the Vicinity of Site For Mine Tailings Ponds, June, 1978.

10. NRC Memorandum, January, 1979.

11. NRC Memorandum, March, 1978.

12. Letter to NRC from owner/operator, October, 1978.

13. NRC Memorandum, June, 1980.

14. NRC Memorandum, May, 1979.

15. NRC Memorandum, November, 1983.

16. Letter to NRC from owner/operator, February, 1979.

17. Inspection and Testing Report, September, 1980.

18. Investigation of liner seam separation, May, 1981.

19. Assessment of liner requirements, July, 1978.

20. Recommended changes in liner system, July, 1979.

21. Letter to NRC from owner/operator, January, 1978.

22. NRC Memorandum, June 5, 1979.

23. Letters to NRC from CoE, August ,1979, November, 1979, and August, 1981.

24. NRC Memorandum, March, 1981.

25. Letter to NRC from owner/operator, January, 1981.

26. NRC Memorandum, September, 1981.

27. NRC record of telephone conservation, October, 1981.

28. NRC Memorandum, January, 1982.

29. Letter to NRC from owner/operator, June, 1983.

30. Assessment of pond liner system, July, 1983.

31. Letter to NRC from owner/operator, September, 1983.

32. Draft NRC Memorandum, November, 1983.

EPA-287 (Cin.)
(4-76)

SECTION 7

INTERVIEW REPORTS

INTERVIEW NO. 1

Louis J. Capozzoli
& Associates, Inc.:
Geotechnical Engineers
10555 Airline Highway
Baton Rouge, LA 70816

Dr. Louis J. Capozzoli, Jr.
Mr. Glynn Gautreau
(504) 293-2460

MEESA:
Masood Ghassemi
Michael Haro

10 October 1983

Summary

- Recompaction of the native Louisiana clay can produce permeabilities in the 10^{-8} to 10^{-9} cm/sec. range. Because of its impermeability and abundant supply, clay is an ideal material for lining hazardous wastes landfills and surface inpoundments in Louisiana. Because of this, and the vast and satisfactory experience with large-scale clay-lined facilities, there should be little justification for use of FML in Louisiana. Also, the current FML installation practices cannot ensure the integrity of such liners in full scale service.

- Because of the high water table in Louisiana, excavated facilities would be located in the ground water which provides a positive pressure and hence an added factor of safety against release of leachate in the event of liner failure.

- Facility construction which has proved successful in Louisiana consists of site excavation, and lining with 3 to 5 feet of recompacted clay, with recompaction being carried out wet of optimum and aimed at elimination of the air spaces. Proctor density compaction level is considered an inappropriate criterion and hence, is not used in judging the adequacy of the completed liner.

- Desiccation cracking of clay liners has not been a problem in Louisiana for excavated facilities because of the high water table, the construction method which involves use of a relatively thick liner and compaction wet of optimum, and the practice of waste enplacement as soon as practicable.

- The Louisiana's successful experience with clay liners can be duplicated in other regions of the country (including the arid zones) provided that (a) the clay is thoroughly mixed and particles greater than 1 in. are removed, and (b) adequate water is added to attain a uniform moisture content of 5% or more wet optimum.

- There is no liner material (clay included) which will not be attacked by certain chemicals under certain conditions. Avoiding excessive leachate generation and accumulation is key to protecting liners against such attacks. Liner-waste compatability tests should use real waste/leachate as the test solution and not pure solvents as have been used in some previous studies.

- Compilation and analysis of performance data from full scale facililities to establish correlations between performance and the design and construction practices used is an important area for R & D work.

Background

Louis J. Capozzoli & Associates, Inc. is a geotechnical engineering firm that offers soil consulting services to industrial concerns, primarily in Louisiana but also in other southern states. Dr. Capozzoli is the president of the firm and has been a soil consultant for more than 2,500 soil and foundation projects. He has worked with nearly all types of waste facilities used in Louisiana, especially below ground facilties. Dr. Capozzoli's expertise includes:

- An intimate knowledge and understanding of soils, especially Louisiana soils.

- Use of specific laboratory apparatus to determine soil properties.

- A working experience with soil-structure interaction.

Because of abundant supply of a very impermeable clay in Louisiana, there is considerable interest in and justification for using clay as a liner material for hazardous waste facilities in Louisiana. Because of the high water table conditions, the design and performance of clay-lined facilities in Louisiana and the applicability of technology to facilities elsewhere are of considerable interest. The purpose of the interview with Louis J. Capozzoli & Associates was to obtain information on company's experience with clay lining and on the state-of-the-art surface impoundment technology in Louisiana.

Use of FML vs Clay Liners for Surface Impoundments

- With a choice between clay and 30, 50, or even 100 mils of Hypalon or HDPE, clay is better. An FML cannot be installed without some damage to the liner material during installation and the integrity of the installed liner cannot be guaranteed.

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- The primary problem with FMLs is poor installation/construction techniques which stem from a lack of trained labor and inadequate quality control and quality assurance.

- Even if a perfect seal is obtained, the liner can be damaged during placement of the backfill.

- There is considerably more experience with clay than with FML and the average dirt contractor knows how to handle clay much better than FMLs.

- Deer have punctured FMLs in Louisiana even though manufacturers/fabricators say that FMLs are resistant to such damage if properly installed.

- There is little justification for installing FMLs in Louisiana where natural impermeable clay is readily available.

Liner-Waste Compatability

- There is no liner that can be used, including clay, that won't be attacked by something. This is especially true of commercial waste disposal facility because of the variety of wastes handled. Some petroleum based materials are known to specifically attack FMLs.

- One answer to this problem is to avoid excessive leachate generation and use of a leachate collection systems.

- Free liquids should not be put into landfills but rather solidified material and sludges surrounded by fly ash or kiln dust to absorb liquids that may come from the waste.

Geotechnical Setting in Louisiana

- Soils in Louisiana are primarily clay with liquid limits of 40 to 50, PIs of 20 to 25 and permeabilities of 10^{-8} to 10^{-9} cm/sec.

- There are some sand and silt streaks in the clay. Sometimes sand strata are found that go 10 to 20 feet down.

- Weather conditions in Louisiana are fairly unique compared to the rest of the country and the terrain is flat. When rain occurs, it does not percolate into the impermeable clay nor can it flow far due to the flat terrain. The result is that, especially in winter, the water table is at or perhaps a few inches above the ground surface.

- The clays in Louisiana have two different strengths depending on locations:

    - In the river bottom lands, the predominant soil is soft gray clay. This generally overlies either the stiff Pleistocene clay or - more often - dense sand. Areas with these soils are now protected from river flooding by levees. The depths of this soft clay vary from 30 feet to more than 150 feet. Bottom land clays are normally consolidated with cohesions of 300 to 400 psf.

    - On high ground, which has never been subjected to natural flooding by the river, the predominant soil is the Pleistocene clay. This is a stiff clay ranging in color from tan to light gray. On most of this high ground, the Pleistocene clay is within 20 feet or less of the ground surface. High ground clays are in a preconsolidated state due to desiccation with cohesions of 1000 to 3000 psf.

- These clays which are 100 to 1000 times more impermeable than concrete, are excellent liner material for hazardous waste disposal facilities. Clay has been in use in Louisiana for industrial retention structures for more than 20 years.

- For bottom clays, the horizontal permeability is usually greater than vertical permeability due to the local alluvial depositional mechanism (seasonal sedimentation resulting in horizontal stratification). Two factors account for this:

    - First, the extremely small individual clay particles are plate shaped: thin with a comparatively large surface. Alluvial deposition usually "arranges" such particles in a horizontally interlocked fashion. Consequently, the "path" for vertical water flow is perpendicular to (and therefore "around") the plates. Potential horizontal flow paths follow a much more streamlined route parallel to the plates. For this reason, horizontal permeability could be greater than vertical permeability by a factor of from 2 to 5.

    - Horizontal permeability is further increased by thin (sometimes "microscopic") traces, lenses, and pockets of silt having comparatively small horizontal areal extends. Such layers are free draining in relation to the surrounding clay. They result from the seasonal periods of low and high (flood) waters carrying different size soil particles. Horizontal permeability increases ranging between 10 to 100 times are possible.

- Surface impoundment construction involving installation of recompacted clay blanket counters both these phenomena. The granular layers are physically sealed off while the clay itself is remolded, thus destroying the horizontal stacking of the platey particles. Final permeability of the clay liner will approximate the in situ clay's vertical value.

Surface Impoundments Design and Construction in Louisiana

- There are three elements to a design study of a proposed site.
  - A feasibility study or preliminary look-over to see if there are any obvious reasons against siting in a particular location.
  - The detailed design phase requires borings inside and outside the area of the proposed facility in order to determine the nature of the soil.
  - The implementation of modifications as necessary due to problems identified (e.g., the occurence of sand strata requiring the construction of a cut-off wall.)
- Construction of a typical surface impoundment in Louisiana is as follows:
  - The pit is dug and lined with 3 to 5 feet of excavated recompacted clay. A general rule of thumb is to use one foot of clay at the base of the impoundment for each 10 feet of water or waste to be impounded.
  - In case of landfills, a leachate collection system is installed and protected with gravel. A monitoring system is also installed.
  - The waste is placed in the surface impoundment. Waste compatibility determinations and what wastes should be banned from a facility are generally left to the owner/operator who knows the waste better than anyone. (Changes may also occur in the characteristics of the waste put into the facility at sometime in the future.)
  - At closure the cap should have a two percent slope to prevent ponding. Caps should be maintained and if subsidence occurs, it should be filled.
  - There should be adequate QA/QC during construction and laboratory tests should be run on the finished liner for permeability and dry density.

Compaction and Permeability Tests in QA/QC

- An example of the specifications for compaction of clay soils is attached to this interview report.

- Compaction of clay used as liner material breaks up sand/silt lenses and prevents flow through these channels.

- Compaction should be aimed at eliminating all air spaces and not necessarily at achieving a certain arbitrary compaction level as determined by the Proctor density test.

  - Compaction wet of optimum is sufficient to ensure elimination of air spaces and development of an impermeable liner with Louisiana clay.

  - Use of a specific compaction design criterion (standard Proctor density) usually requires drying the clay; in so doing permeability is endangered.

  - Permeability, determines water tightness and should not be lessened by unnecessary compaction tests.

- Compaction tests were originally used for roadwork, dams and airstrips which require compaction studies to ensure strength and stability. Surface impoundments require permeability studies to ensure watertightness.

- Laboratory permeability tests of clay can show lower permeability measurements than the actual measured field permeability due to the presence of silt lenses and cracks in the soil sample. Permeability sampling of clay liners is only 2 to 3 inches deep and does not extend through the liner.

- Permeability tests on clay at a secured landfill cell in Louisiana have shown no difference between permeability measured using water and those using actual leachate.

- There is little practical significance to laboratory test results which indicate pure solvents can have an adverse effect on clay impermeability, as such test solutions are poor representation of the actual waste or leachate encountered in a disposal site.

Clay Liner Cracking Problem

- With the exception of above ground facilities with fluctuating waste liquid level, cracking of clay liner is not a major problem in Louisiana due to high water table and precipitation which keeps the soil moist most of the time, and liner construction involving compaction wet of optimum.

- In the above ground facilities with fluctuating liquid level, the clay embankment is subject to cracking in dry weather. Use of above ground facilities is often necessary due to unavailability of land for site expansion and for the problem of encountering water or permeable layers in digging deep pits. For these facilities, the problem can be

TYPING GUIDE SHEET

mitigated by lining the embankment slope with FML, firmly anchoring the toe below the permanent water line.

- FML installation on embankment slopes should be done carefully to ensure liner integrity and water tightness. Anchor depths greater than one foot are required for proper anchoring. The fluctuating water line allows visual inspection of the FML for maintenance purposes.

- If the clay used for liner material is dry such as that in areas, unlike Louisiana, with a lower water table, the clay must be wet and pulverized to a uniform size (clods < 1 inch). It is an expensive procedure in arid locations due to the use of water, but it often may be better than other available systems.

- For a surface impoundment 10 to 20 feet below ground (or a similarly situated landfill with leachate collection and removal system)and with the water table at the ground surface, if a hole or crack occurs in the liner, water will flow into the cell rather than out into the ground water due to the positive pressure supplied by the high ground water table. From the standpoint of ground water protection such a system should thus be fail-safe.

- The primary limitation of geotechnical site evaluation is the possibility of not detecting all major discontinuities in the soil. For example, a 100 foot wide buried old stream bed could be missed by test borings with 200 foot centers.

    - Design specifications cannot account for all such instances and so on-site inspection is essential.

    - Dirt contractors are not always able to identify potential problems during excavation. It is important to have trained geotechnical inspectors on the job.

    - It is possible to design a facility around a geotechnical problem but with discontinuities always possible, proper construction and inspection becomes a critical issue.

- In the stiff preconsolidated clays of Louisiana bore holes can remain open for many years. In such clays it is too risky to bore down to the aquifer to monitor it due to the chance of contamination. Shallow monitor wells are better in this situation. Bore holes are filled with a cement-bentonite mixture to seal them.

- As with any construction job, contractors, especially the dirt contractors, must be able to meet the requirements of the job as specified prior to work initiation in order to ensure adequate QA/QC.

- Sloughing of the clay liner on slopes due to wave action does not appear to be a problem in Louisiana and riprap is not generally required. Levees are made wide enough to drive a truck onto them.

EPA-287 (Cin.)
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- Growth of vegetation through the liner is generally not a problem. Trees sometimes grow on embankments. Roots can increase retention on side slopes but soil on slopes with vegetation dries out more quickly than soil with no vegetation. Animals can damage facilities (i.e. by boring into embankments) and are a constant problem in Louisiana.

- Recently there is a tendency for industry to opt for on-site rather than off-site waste disposal because of the liability of waste generation in ultimate waste disposal. However, a problem with on-site disposal is that a number of plants in Louisiana were built 20 to 30 years ago and are not necessarily appropriate for waste disposal and additional land is not available adjacent to the plant.

Some Examples of Facilities Handled by Capozzoli

- No facility designed by Dr. Capozzoli and his firm and inspected during construction including those with up to 25 years of operation has suffered loss of contained fluids. Examples of these successful installations are:

    - A 110-acre reservoir was built on a flood plain over 20 years ago with 2 foot clay bottom and sides. It holds a maximum of 20 feet of water but the level fluctuates according to the flow of water in the river. This facility used compacted clay from nearby hills. Retention requirements were not as stringent as present day waste regulations but it is still operating successfully.

    - A cooling pond and gypsum stack for a phosphoric acid plant were first installed by another firm 10 years ago as a 300-acre pond and later expanded by this firm to 500 acres. It was built of in situ clay. Monitoring well data indicate no migration of liquids from the pond.

    - A gypsum storage pond was built with secondary and tertiary dikes around it in case of failure. Soil borings every 250 feet revealed clay with sand/silt lenses. The pond was excavated to a maximum of 5 feet deep and contains gypsum stacks 60 to 70 feet high. Even with that much head, there has been no leakage in 12 years. Gypsum is considered a "special" waste in Louisiana.

Research and Development Needs

- There is a need for studies of real time experience with disposal sites, collection of actual performance data and making this information available to design and construction engineers.

- There is considerable experience with various liner construction techniques and fundamental parametric studies (e.g., to determine optimum lift thickness or compactive effort) would be of little value in advancing the state-of-the-art.

- Laboratory studies should be field-type studies in realistic settings, e.g., using actual leachate and not pure chemicals in waste-liner compatability studies.

SPECIFICATIONS FOR COMPACTION OF IMPOUNDMENT LINERS OF CLAY

After the subgrade where fill is to be placed has been approved by the engineer, the contractor can start his compaction operations. Compaction required of the subgrade is described in the job specifications and shall be performed as described herein. No fill shall be placed on any area of the subgrade which has not been accepted by the engineer.

One week prior to the contractor placing any fill on the site, he shall inform the engineer of the borrow pit he desires to use. The engineer will check the borrow pit to insure that the soil meets the specifications for the fill. The engineer wil also obtain the necessary fill control curves. Initial acceptance of the soil in the borrow pit does not mean acceptance of the entire borrow pit since the soil encountered in the pit can change.

Clay soils used for fill shall have a minimum PI of 15. The material shall be placed at least 5% wet of optimum. These moisture contents may be reduced if necessary to ease trafficability of the contractor's equipment but the moisture contents shall never be drier than 3% above optimum. Each layer of fill shall be rolled with three complete coverages of the compactive equipment. No percent of compaction will be required. The sole requirement will be the material compacted sufficiently to eliminate all air spaces between the individual clay pieces.

The thickness of lifts used shall be no more than the height of the teeth on sheepsfoot rollers. Generally, for 48 inch diameter or smaller drum rollers, the maximum compacted lift thickness acceptable is 6 inches. For rollers with drums of 60 inches in diameter and larger, with teeth about 9 inches long, a 9 inch final compacted lift thickness will be acceptable.

While, generally, sheepsfoot rollers are most suitable for compaction of clay soils, the contractor may use spiketooth rollers, rubber tired rollers, or any fill compaction equipment that has sufficient mass to compact the soil. Generally, the drums of sheepsfoot rollers should be filled with water, or for additional weight, with both water and sand. Tractors or other vehicles used primarily for hauling WILL NOT be allowed as fill compaction equipment. The contractor should also have smooth wheel rollers to seal the working area at the end of the day's operations so that overnight rains will not saturate the soil and delay his work. These rollers should also be used to seal the surface whenever rainfall is imminent. The soil engineer will instruct the contractor to modify or remove from the site any equipment that in his opinion is not capable of compacting the fill properly.

INTERVIEW NO. 2

State of Ohio Environmental
 Protection Agency:
361 E. Broad Street
Columbus, OH 43216

Russell B. Stein
Division of Public Water
 Supply
(614) 466-8307

Christopher L. Bowers
Division of Hazardous
 Materials Management
(614) 462-8413

12 October 1983

MEESA:
Masood Ghassemi
Michael Haro

Summary

- There are some 40 to 55 surface impoundment facilities in Ohio handling an estimated one million ton per year of hazardous wastes. These facilities are generally older facilities which were placed in service at a time when regulations governing siting and design/construction of such sites were considerably less stringent than current RCRA requirements. They are not engineered sites and, hence, are not suitable for design versus performance case studies.

- Under current procedures, approval of new sites in Ohio requires: (1) a preliminary geological screening of candidate sites, (2) more detailed geotechnical investigation of the selected site, (3) submission of detailed design and specifications to the state, and (4) modifications to the plans as deemed necessary by the state.

- Since all liners may leak at some time, hydrogeological characteristics should be the most important consideration in siting hazardous waste disposal facilities. Siting in geologic formations such as thick deposits of low permeable glacial till can provide an added factor of safety against catastrophic liner failures.

- Waste disposal siting in Ohio emphasizes: (1) taking advantage of the natural geology which is suitable for waste disposal in many areas, (2) relying on the absorptive capacity of underlying strata to attenuate waste migration, and (3) case-by-case examination of proposed sites.

- Any revisions to existing RCRA regulations should: (1) place a greater emphasis on siting in geologically suitable formation than on the use of the state-of-the-art liner technology, and (2) more clearly define the "uppermost" aquifer and the procedure for locating/constructing ground water monitoring wells.

- Laboratory permeability test results for in situ materials are generally not very reliable because of the inadequate and non-standardized nature of the current sampling and testing techniques and the difficulty in obtaining undisturbed and representative samples.

Background and Objective

Geologists in the Division of Public Water Supply of the State of Ohio are responsible for the hydrogeologic assessment of all proposed land disposal facilities. This activity is carried out as a technical assistance function to the Division of Hazardous Materials Management which reviews hazardous waste facility permit applications. The State of Ohio is currently developing land disposal facility permit standards for Phase II (A-C) authorization of their program under 40 CFR Part 123 of RCRA.

The objective of this interview was to: (1) obtain information on the state-of-the-art surface impoundment technology in Ohio, (2) identify surface impoundment(s) suitable for design versus performance case studies, (3) collect information on the site(s) identified for the case studies, and (4) obtain perspectives of this regulatory agency on various aspects of design, operation, permitting, R&D needs, etc., of hazardous waste surface impoundments and other land disposal facilities.

Surface Impoundments in the State and Suitability for Case Studies

- The existing hazardous waste surface impoundments in Ohio are older facilities which were placed in service at a time when there were no rigorous regulations governing their design, construction, and operation. These facilities are not engineered sites and very little, if any, data are available on their original designs and any modifications which might have been implemented since they were first placed in service. Because of these considerations, it is very doubtful that any of the sites in Ohio would be a suitable candidate for case studies whereby the actual performance is to be compared with projected performance based on design.

- The state approved 336 hazardous waste facility permits in 1981. Up to 55 of these facilities contain one or more surface impoundments each, and about 30 percent of them are used for disposal. Approximately one million ton of hazardous wastes were impounded in 1982.

- Most non-hazardous lagoons in the state are over 10 years old, are unlined, and are not being monitored for ground water quality impact. Many of those older impoundments were purposely constructed to percolate wastes to ground water in order to avoid the requirement for obtaining NPDES permits. (There were no wastewater discharge requirements for ground water.) Examples of these impoundments include pickling liquor wastewater ponds at certain steel industry plants.

Siting Considerations and the Importance of Hydrogeological Suitability

- The hydrogeological setting in some parts of the state is very suitable for effective containment of hazardous wastes. In some areas there are 20 to 30 feet of native clay with a permeability of 10^{-7} cm/sec or less. The low permeability and the depth of clay layer can provide

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adequate waste isolation and, hence, ground water protection. The clay layer also provides significant waste absorptive capacity and it may take as much as 2000 to 3000 years before waste can penetrate a very thick layer of low permeability clay.

- Because of the above considerations, the state has always placed a much greater emphasis on siting hazardous waste facilities in suitable geological locations and on relying on waste attenuation capacity of the clay than on relying on newer liner technologies which may be more suitable for use in other parts of the country.

Approach to Permitting New Facilities

- The state review and approval of a site for handling hazardous waste is on a case-by-case basis. The following steps are required:
    - Preliminary geological review of the proposed site (or candidate sites) to identify general hydrogeological suitability or major constraints. This involves the use of existing data or direct field observations and will aid in making a preliminary determination on the potential for ground water contamination. Some data sources include geologic reports, hydrogeologic maps, drilling records, water quality data, and any other information on the subsurface in and around the site. It is important that the preliminary review should be conducted prior to land acquisition by the facility operator.
    - Detailed geotechnical investigation at the proposed site (or leading candidate sites) to better define specific conditions. This investigation involves on-site boring and is aimed at developing detailed information on site hydrogeology. Although the number and spacing of soil boring is not specified, such considerations must be to the satisfaction of the state in order to gain approval to proceed with detailed design and construction. If borings indicate presence of sand or silt lenses, the state may restrict construction to areas without such discontinuities or may require removal of such discontinuities. The state also requires grain size testing of boring material to detect silt and sand lenses.
    - Preparation of detailed design and specifications. The state thoroughly reviews the detailed design and specifications developed by the site applicant and suggests revisions as necessary.
    - Modification to proposed designs and specifications to incorporate changes suggested by the state.
- The case-by-case analysis would avoid use of predetermined standards and criteria for site suitability which, in some cases, can result in eliminating some otherwise suitable sites from further consideration.
- In using permeability test results, the state is well aware of the limitations of the tests and the difficulty and cost of obtaining an adequate number of representative samples.

Miscellaneous Regulatory and Other Considerations

- Unless the ground water monitoring system is tailored to the specific hydrogeological features of a site, it may prove inadequate in providing a true picture of the background conditions and changes in water quality. In many areas it would be very difficult to identify background ("upgradient") and impacted ("downgradient") ground water (e.g., due to possible presence of isolated "pockets" of ground water underneath the sites).

- The term "uppermost" aquifer which appears in RCRA Interim Status Standards requires some clarification. The ground water monitoring requirement should also make a distinction between monitoring true usable ground water versus seasonal moisture.

- Since the current Interim RCRA regulations require the use of liners, the state regulations which are currently under development will also have to require use of such liners. Since federal regulations are usually not stringent enough for the state conditions, the state will continue to emphasize location factors and will require ground water monitoring even at double-lined facilities. Use of coupons to monitor liner conditions may also be required.

- Compared to surface impoundments, landfills are more permanent structures and more difficult to repair. A leaking surface impoundment can be remedied by draining out its contents, inspecting the liner conditions, and repairing any damage; such repairs are generally not economically feasible with a landfill.

Research and Development Needs

- Waste-liner compatibility should be studied under realistic conditions and the results should be interpreted in terms of implication in full-scale facilities. The compatibility tests which have been reported in the literature have used chemicals (e.g., pure solvents) which are not representative of actual wastes which will be in contact with the liner. Moreover, the reported degradation of liner represents the effect on the very top surface layer and may be of little consequence to a 10- to 50-feet thick liner.

- The issue of the degree of hazard and what wastes should be excluded from land disposal sites must be addressed.

- Standard sampling and testing protocols should be developed for liner permeability evaluation and compatibility.

- Basis and criteria should be developed for design of ground water monitoring system (e.g., with respect to well depth).

INTERVIEW NO. 3

Staff Industries, Inc. 78 Dryden Road Upper Montclair, NJ 07043	Dr. Charles Staff (201) 744-5367	MEESA: Masood Ghassemi

13 October 1983

Summary

- From the fabrication standpoint, there are no differences between fabricating sheets for lining surface impoundments or landfills and the predecessor liner technology assessment report prepared for EPA covers the important factors in developing adequate liners for both types of installation.
- Lack of feedbacks from operating facilities has been a major obstacle to proper evaluation of the performance of various designs and installation practices.
- Liner failures are mostly due to poor field installation and use of inappropriate liner material. Field installation problems can be minimized by use of larger sections (where considerable seaming is done in the factory), good field supervision, and reliance on the previous experience of the individuals who will be doing the actual installation. Provided that it is properly installed, FML is a material of choice for lining waste disposal sites.
- Providing cover for a liner is extremely important in preventing damage from the heat of the sun and minimizing problems stemming from vandalism, pinholes, and chemical incompatibility.
- Liner-waste compatibility has been unnecessarily overemphasized. The leachate or waste materials commonly encounteed is largely water, and its composition in no way resembles pure organic solvents which have been used in certain liner-waste compatibility studies.

Background

Staff Industries, Inc. is an FML fabricator with engineering and sales representatives throughout the country. At its production plant in Detroit, MI, the company fabricates Hypalon, PVC, and CPE liners. Historically only on limited occasions has the company been engaged in the actual installation of liners, and these occasions were necessitated by the poor job that certain commercial installers were doing with the Staff products. However, currently the company does install quite a number of projects because engineering firms are specifying that the lining supplier do the installations or at least provide technical supervision of the installation. Some company representatives have been qualified to do installation work and several of them now have field crews that perform this work. Dr. Charles Staff, the founder of the company, has been a technical leader in the FML industry and has often been referred to as the father of the liner industry.

Surface Impoundment Versus Landfill Applications

- From the standpoint of fabrication, there is essentially no difference between fabrication liners for use in landfills (LF) or surface impoundments (SI). The predecessor EPA study involving the "Assessment of Technology for Constructing and Installing Cover and Bottom Liner Systems for Hazardous Waste Facilities" is a thorough study and the information contained in the final report for the project would apply to liners in both applications.

- A major problem in evaluating the performance of liner in SI or LF application is the lack of feedbacks from owners/operators after the facility has been placed in service. The absence of such feedbacks and the difficulty of obtaining operating data from full-scale facilities make it almost impossible to evaluate performance versus engineering design and construction practices used. What little performance data which have been analyzed in the literature have often been based on inaccurate or inadequate second-hand information.

Field Installation Problems and Corrective Measures

- Two major causes of some of the reported liner failures are poor field installation and use of inappropriate liner material. Field installation problems can be minimized in a number of ways, including the following:

    - Minimizing field seaming where possible by use of larger liner sections whereby much of the seaming has been done in the fabricating plant. Factory seams are produced under more controlled and favorable conditions and receive greater QA/QC attention. These seams are thus generally more reliable than field seams. To this end, Staff Industries fabricates liner sections into large pieces (up to 100 feet wide and in lengths up to 6000 pounds) using solution bonding.

    - Providing good field supervision and appropriate technical assistance to the installer. Adequate QA/QC program is essential to achieving good performance for the completed liner. Although QA/QC procedures are relatively simple, the QA/QC representatives are often not thoroughly familiar with such procedures and requirements. Liner fabricators and manufacturers can also provide much of the needed technical assistance to the installers.

    - Use of experienced workes who will carry out the actual installation. The experience of the individuals who will be assigned to an installation task rather than of the installing company per se is the important factor in ensuring high qualitywork. It is not uncommon that an installing company, selected for a job because of its extensive previous liner installation experience, assigned inexperienced crews and supervisors to the job and hence produced some inadequate products. Thus, in writing specifications and selecting installers, the emphasis should be on the experience of the individuals who will be committed to the job rather than on the experience of the company per se.

- There is no practical solution to the common tendency of owners/operators to select low-bid installers who may not provide quality installations. Perhaps the European practice of discarding the highest and the lowest bids in the initial screening is a partial solution in that the very low bidders are eliminated from the competition.
- During construction, it is not a good practice to chase away large game animals which may appear on the liner surface as liner damage may result when the animals run (versus walk gently) over the liner.
- Contrary to what has been asserted, accidental or careless dropping of lighted cigarettes on the liner by workers during installation will not cause permanent damage to the liner. The liner material has generally a high ignition point and will not burn. It may temporarily soften slightly, but there will be no permanent damage.

Importance of Liner Cover

- Providing and maintaining an adequate cover is extremely important for ensuring long life and adequate performance. A good cover provides the following:
    - It protects the liner against damage from the heat of the sun. Even though plasticizers in the liners are high boiling point compounds, they nevertheless have a certain vapor pressure and are susceptible to slow volatilization. Actual measurements have indicated that the temperature at the exposed liner surface can reach and exceed 200°F. This will result in gradual loss of plasticizer and hence stiffening of the liner material. This kind of damage to PVC liners resulting from high surface temperature has often been erroneously attributed to the uv radiation damage.
    - Since it "hides" the otherwise exposed sections of the liner, the cover reduces damage due to vandalism. In certain canal lining applications where the liners remained exposed, vandals removed sections of the liner for sale or personal use (e.g., roofing).
    - Soil cover can restrict flow through pinholes. In actual field tests where a soil cover was placed on a liner containing pinholes and the liner was then removed and examined for pinholes by visual means, no pinholes could be observed. The fine soil particles cover the pinholes and can conceivably restrict leakage through such holes.

(Incidentally, given the current technology, a reputable manufacturer will not produce a liner with pinholes.)

- Cover attenuates movement of leachate or waste constituents and hence their contact with the liner. Because of this attenuation, organics and other potentially harmful constituents in the leachate would not be in direct contact with the liner. Even in cases where the liquid in a surface impoundment might separate into a thin organic phase on the top and a liquid phase underneath, the organic material on the top will generally be prevented from contacting the liner on the sloping sides, because of the upward capillary seepage of the water from the lower phase. This attenuation capacity of the soil cover can also act as a waste "equalizer", thus preventing the liner from "seeing" wide fluctuations which may occur in the characteristics of the input waste or resulting leachate.

Other Design Considerations

- Even though waste-liner compatibility tests can provide valuable data for selecting a suitable FML, a problem which is often encountered is that the characteristics of the actual waste which will come in contact with the liner is not known at the time of liner design and the actual waste may have a different composition than that used in the compatibility testing. In general, the issue of liner-waste compatibility has received an undue emphasis and in certain compatibility studies, chemicals (e.g., pure acetone) which are totally unrepresentative of the leachate or liquid waste which will contact the liner have been tested. In the actual disposal environment, the leachate or the liquid waste is composed largely of water containing generally less than one percent impurities.

- Gas formation under the liner is generally due to organic decomposition and/or fluctuating water table (in the case of surface impoundments). Providing 2 to 3 percent bottom slope should allow adequate gas venting.

- Provided that it receives adequate QA/QC attention during installation, liner connections to structures should not present a major design or installation problem. Use of unreinforced material around connections is generally preferred as it can adequately withstand the normal expansion and contraction.

- Muskrat damage to liner in surface impoundments can be minimized by placing a gravel cover up to the water line. Muskrats will find digging in gravel unproductive and will leave the area.

- Use of geotextiles as support material for the liner is generally too costly and, depending on the situation, may not be worth the investment. Foundation and support surface preparation work, however, are very important for achieving good liner performance.

Perspective on Clay Versus FML

- Provided that it is installed properly, FML would be preferred over clay for lining landfills or surface impoundments, primarily because of the much higher impermeability of FML. Permeabilities of less than 10^{-12} cm/sec for PVC and less than 10^{-14} cm/sec for Hypalon have been measured. In comparison, permeability of typical recompacted clay is in the 10^{-8} to 10^{-7} cm/sec range. The importance of good installation job in achieving good performance is not only true for FML but also for other structures, even a steel tank which if installed improperly may leak.

- The EPA is concerned regarding the use of clay for linings since although clay will impede the discharge of wastes into the underlying water due to its low permeability, eventually wastes will wash through. In the case of FML, permeability is much lower and most specifications for hazardous wastes are requiring that drains be placed on top of linings and then covered with earth. This is to insure that any seepage through the covering will be removed from the top of the FML.

Research and Development Needs

- Developing proper specifications for doing good installation is an important area for R&D work.

INTERVIEW NO. 4

Emcon Associates: 1435 Schulkill Road Pottstown, PA 19464	John Pacey (215) 327-4340	MEESA: Michael Haro

8 November 1983

Summary

- Design of liners for surface impoundments has to take into account factors such as stresses under the discharge inlets, continuous liner-waste contact, wave action, surface fluctuations, air/water interface problems and differences between stresses on the bottom and on the side slopes. Surface impoundments are less permanent structures than landfills and offer more flexibility in liner design.

- Selection of a liner compatible with a given waste (which might also change in characteristics after a facility is placed in service) is a key factor in ensuring liner longevity. The basis for liner selection and support data should be made available to facility owners/operators who are often not fully aware of compatability consideration and importance of accepting only compatible wastes.

- Liner repair is especially difficult when the liner has been in contact with the waste for a relatively long time.

- Hydrogeological considerations are the most important factors in designing adequate surface impoundments.

- Documentation of successes and failures of operating surface impoundments and development of a technical manual on seaming techniques and a manual which discusses how various elements of facility site selection, design, construction, operations, monitoring maintenance and repair come together in developing an adequate facility, are some key areas for R&D work.

Background

- Emcon has about 80 people on staff that exclusively design municipal, industrial, and hazardous waste treatment, storage and disposal facilities. Systems designed by Emcon include both commercial and on-site facilities containing landfills, land treatment, and surface impoundments lined with soil and/or FML. The following two recent Emcon publications review the state-of-the-art and the company's "philosophy" of site selection/suitability, design, operation, and monitoring of hazardous waste land disposal facilities:

    - "The Use of Liners for Containment at Hazardous Waste Land Disposal Facilities", to be published in Pollution Engineering.

    - "Technical Manual: Hazardous Waste Land Disposal/Land Treatment Facilities", final draft submitted to Army Corps of Engineers in Huntsville, Alabama, September 1983.

  Mr. John Pacey is the head of Emcon's liner design section and is an authority on FML use in hazardous waste facilities. The objective of this interview was to obtain his perspectives on various aspects of site selection and suitability; liner material selection, design, performance; and R&D needs for hazardous waste surface impoundments.

FML Design for Surface Impoundments

- Design of liners for surface impoundments has to take into account a number of additional factors not generally applicable to landfills. These factors include stresses under the wastewater discharge points; continuous contacts of the liner with the waste (at least at the bottom and on most of the side slopes); wave action, surface fluctuations and air-water interface problems; and differences between the stresses on the bottom and on the side slopes.

- Selection of a specific liner material for a job is generally based on considerations of waste compatability; cost; ease of installation and repair (given the particular size and configuration of the impoundments); maintenance requirements and specific site conditions (e.g., potential damage due to traffic, animals, wind, precipitation, ground movement, and gas formation). Except for the waste compatability factor, most commercial FMLs can meet these requirements when properly designed.

- Of various types of liners which are commercially available, HDPE, CPE, and CSPE are considered generally suitable for surface impoundment applications. Other materials may be suitable based on performance criteria, properties, and cost. In selecting a liner material, the designer generally relies on compatability information available in the literature and/or obtainable from liner manufacturers and the performance experience in related applications (past projects). Compatibility data and experience must be developed and available before final selection of an FML for a given project.

- Large commercial hazardous waste management facilities practice segregated waste disposal as a control method to reduce liner-waste incompatability problems. Incoming wastes are tested and discharged to different ponds or storage areas having appropriate liner types. Thus, certain facilities operate "dedicated ponds" where only one type of waste (e.g., oily wastes) is handled in a pond. In this connection it is very important that site operators be provided with the documentation of the basis for liner selection and facility design so that he can pass judgement on compatability of various waste loads before accepting them. Liner failure or damage resulting from waste incompatibility should be anticipated as being generally more prevalant where a large variety of waste materials are accepted and among smaller facilities where the owners/operators may not be fully aware of the incompatibility problems and where there may be fewer receiving facilities and insufficient storage areas to segregate waste into a compatible containment environment.

- There is generally a greater flexibility in designing liners for surface impoundments than for landfills since surface impoundments are viewed as less permanent and more amenable to future corrective measures.

Leak Detection Systems and Repairs

- Reliable and cost-effective methods currently exist for timely indentification of liner leaks but generally do not assist in pinpointing the leak area. Once the leak failure area is found repairs must be implemented. The various proposed liner repair methods and their effectiveness have been reviewed in a recent Emcon report prepared for EPA/MERL-Ci.

- It may be difficult to repair an FML that has been in contact with the waste and/or the elements for a number of years, because of the difficulty of obtaining a good seal or bond between the new and the old (cured) liner materials.

- The need for and the type and sophistication of the leak detection system (including the number and location of the observation and ground water monitoring wells) is very site- and situation-specific. At present, relatively few existing surface impoundments have leak detection systems.

- Sites with multiple disposal impoundment units should be designed so that the performance of individual units can be independently and continuously monitored and assessed using data from leachate/leak detection systems and ground water monitoring wells and water balance calculations.

Storage and Shipping Considerations

- Most manufacturers have quality assurance programs and their products generally meet their stated specifications. Damage to liner, however, can occur during liner transportation to site and its storage on-site. Improper stacking, vandalism and weathering are common causes of damage to liner during storage and can be managed through use of certain (often common sense) precautions.

Siting and Other Design Considerations

- Availability of land on the premises is generally the basis for site selection for on site disposal. Site selection for off-site facilities, however, is a more elaborate effort involving preliminary assessment of potential candidate sites, screening of the more promising candidates and detailed feasibility and geotechnical studies. In addition to the technical criteria, political and social considerations are important considerations in selecting these sites since site selection rationale (especially for the larger sites) receive considerable scrutiny by the public and the regulatory agencies.

- Site hydrology is generally the most important single factor considered in siting of surface impoundments (and landfills). Other important site-specific technical considerations relate to soil composition, soil permeability, seismicity, geotechnical conditions, drainage/flood conditions, access, transportation, etc.

- During a geotechnical investigation, it is impossible to look at every bit of soil beneath the facility. The use of statistical analyses of soil boring/testing data, good inspection techniques during construction, and special design elements to mitigate the impact of site hydrogeologic conditions, will help assure adequate impoundment performance.

- New facilities can be constructed at sites with contaminated soil/water due to neighboring facility or past on-site disposal practices, if the facility is designed so that it can be demonstrated that no containment contribution is made by the new operation.
    - Once ground water contamination occurs, the source and extent of the contamination must be identified. However, it is difficult to monitor or investigate beyond property boundaries. A possible complication is that the direction and magnitude of ground water flow may change, possibly several times over a number of years, caused by groundwater table fluctuations (naturally occurring or induced by man).
    - These concerns can be eliminated by designing a containment and monitoring system that can adequately demonstrate the new facility's performance. The new facility should have as a minimum a double liner; a triple-lined system is also possible.
- The difficulty of predicting future changes in waste characteristics (stemming from changes in plant operations/processes) so that such changes can be addressed in the design is a major reason for some cases of past liner failure after a few years of operation. Any time the character of the discharge stream to the surface impoundment is changed (physically or chemically) the compatibility with the liner system must be reviewed in detail.
- Where clay liners are used for containment, Emcon has developed soil permeability tests which closely approximate actual field conditions. Density-permeability relationships are first established using water as the permeating fluid; tests are then repeated using the actual wastewater to be impounded. Laboratory permeability tests are run with a back pressure of 100 psi using the falling head method. A minimum of 2 volumes of permeating fluid are passed through the sample.

Research and Development Needs

- There is a paucity of information on hazardous waste facility case histories that provide detailed analysis and documentation of performance (failures and successes).
- There is a need for a technical manual that discusses in some detail how all of the elements of facility site selection, design, construction, operation, monitoring, maintenance and repair fit together.
- A comprehensive manual on seaming various types of FML should be prepared.
- There is a great need for independent verification of suppliers' claims as to the capabilities of various FML types.

INTERVIEW NO. 5*

State of Louisiana:
Hazardous Waste Management Division
P.O. Box 44066
Baton Rouge, LA 70804

Gerald D. Healy, Jr.
(504) 342-1227

MEESA:
Michael Haro

10 November 1983

Summary

- As a result of recent changes in the state's hazardous waste list (to conform to that of EPA) and the state's effort to discourage the use of impoundments for hazardous waste, there will probably be less than 50 impoundments are used for treatment.

- Approval of new sites in Louisiana requires: (1) geotechnical information including data from borings on 200 foot centers to a depth at least 30 feet below proposed SI depth and definition of permeable zones and discontinuous lenses; (2) a synthetic liner plus three feet of clay with a pereability $\leq 10^{-7}$ cm/sec and (3) design data on liners, the leachate detection/ground water monitoring system, operating plan, and drawings and construction specifications.

- Ground water monitoring programs should be site- and situation-specific and should be for specific indicator parameters based on pond content, constituent mobility, test reliability, etc. Since most of the facilities in the state are in or near the water table and well above potable water aquifers, the use of drinking water parameters in EPA regulations is of questionable value. Monitoring of a deep potable aquifer is of no value in identifying a potential problem for timely remedial actions.

- Whether or not waste-liner compatibility studies are required depends on available data and experience that exists for the given waste and liner types.

- Areas requiring additional research and development include () evaluation of compatibility of various FMLs and clays with different waste types, (b) establishment of appropriate procedures and QA/AC methods for installation and jointing of FMLs, and (c) compilation of data on mobility and persistence of various hazardous waste constituents.

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*In this interview, Mr. Healy communicated his views in writing by responding to a set of questions submitted to him by MEESA.

Background

- Most disposal facilities in Louisiana are in or near the water table. Because Louisiana clay is very impermeable and is in abundant supply, it has been widely used as a liner material. The state has had hazardous waste disposal permitting requirements in effect since 1979 and has recently applied for Phase II authorization. Mr. Gerald D. Healy, Jr. is the Administrator of the State Hazardous Waste Program and is most intimately familiar with the technical and regulatory aspects of hazardous waste surface impoundments in the State of Louisiana.

General

- Louisiana has recently changed its universe of wastes to be identical with that of EPA. They are currently in a renotification process since most of the original notifications to Louisiana included many waste streams which are not in the federal program. Although the State estimates that over 200 impoundments were originally in the program, the current changes in conjunction with efforts to discourage the use of impoundments for hazardous waste will probably result in under 50 impoundments under the State's control. In nearly all cases, impoundments are used for treatment.

- Louisiana has applied for Phase II authorization under RCRA. Regardless, the State has permitting requirements that must be met. As previously, the State discourages the use of impoundments in cooperation with their Air Quality Division. Any proposal for an impoundment must demonstrate how the applicant will comply with the regulations.

Site Selection/Suitability

- Site selection is the responsibility of the applicant. An applicant should consider the geology, hydrology, etc., since the permit application must demonstrate compliance with the regulatory requirements.

- The regulations provide for geological information which must be provided in the permit application. Generally, it requires borings on 200 foot centers to a depth at least 30 feet below the proposed impoundment depth. Spacing between borings may be altered if necessary to clearly define the shallow geology. Data from the borings must include the drillers log and soil analyses as necessary to define the stratigraphy. Care is necessary to properly define the characteristics of alluvial deposits so as to define permeable zones versus discontinuous lenses, etc.

- If an impoundment is to be located in an area with existing contamination, a methodology for assessment of the new facility is necessary. Examples would be a new impoundment which would handle different materials so that monitoring would be for specific indicator parameters rather than TOX and TOC, or use of double liners with a leak detection system between the liners.

Impoundment Design

- Since most impoundments are located in the industrial area between Baton Rouge and New Orleans and in the Lake Charles construction area, soils are generally of an alluvial nature. Past construction practices frequently included recompacted clay liners and some also provided synthetic liners. State regulations now in effect require a synthetic liner plus three (3) feet of clay with a permeability not greater than 10^{-7} cm/sec or equivalent.

- The required design data in a permit application includes details on the clay and synthetic liners, the leachate detection/ground water monitoring system, the earthwork design and operating plan, etc.

- Detail design drawings and specifications must be submitted for approval prior to permitting. Construction may not begin prior to permit issuance. The design must include details on the materials, construction methods and quality assurance.

- Whether or not waste-liner compatibility studies are required depends upon the level of knowledge from the literature and experience that exists for the waste and the soils and synthetic liners already available. If satisfactory data is not available, pre-construction compatibility testing will be necessary.

- Synthetic liners are beneficial in some cases. In situ clay is helpful in addition to engineered liners but often is slickensided, allowing migration of such materials as ethylene dichloride, trichloroethylene and perchloroethylene. As previously noted, the State requires a minimum of three (3) feet of 10^{-7} cm/sec recompacted clay in addition to the synthetic liner.

- There are no specific design requirements on the construction of impoundment embankments. Such embankment design must be submitted and approved prior to construction. It must provide for both structural and permeability compliance. In many areas this will necessitate some removal of surface soils to a firm base and keying of the construction into such a base. The construction will be in shallow lifts with suitable compaction and provision of side slopes consistent with the soils used for construction. Suitable erosion control will also be required.

Impoundment Performance

- Monitoring should occur in each permeable zone in which horizontal migration might be expected from the surface to the first zone below the impoundment. The State prefers to monitor for specific indicator parameters based on what is in the pond and considering mobility, concentrations, expected diffusion, ion-exchange, test methodology reliability, etc. Since most of the facilities are in or near the water table, and well above aquacludes to the potable water aquifers, the use of the drinking water parameters and most of the other parameters in the EPA regulations are of questionable value. Monitoring of a deep potable aquifer is of no value in identifying a potential problem in time to make remedial action simple and cost effective, if in fact it is even possible.

- The value of leak detection systems depends on the geology of the site. If the first permeable zone under an impoundment is a potable water aquifer, a second engineered liner with a leak detection system between the required liners should be provided. This may also be true if the first permeable zone is much deeper than the bottom of the impoundment.

- Regarding monitoring of facilities with more than one impoundment or more than one type of technology on-site, if the wastes involved are sufficiently different, different specific indicator parameters can be used. In other cases, the location and/or depth of monitoring wells may provide adequate delineation between facilities. Although the regulations do not directly address this, they allow the Administrative Authority to require the monitoring system design to provide the needed data, including well placement and test parameters.

- It is difficult to predict what problems may be encountered before a facility receives a permit and thus hard to design remedial action beforehand. Such premature corrective measure scenarios would be primarily a paperwork exercise.

- When an impoundment failure is suspected or demonstrated, the permittee is required to evaluate the problem, including definition of the plume. He is then required to submit a remedial action plan for approval, and must then carry out the plan. The State has experienced several cases of soil and water contamination and has some firms under orders to carry-out investigations and remedial action. In most of these cases it is not currently possible to define a point source of the contamination.

Research and Development Needs

- More data is needed on the effectiveness of synthetic liners and on the compatibility of clay and synthetic liners with various materials. Data on the jointing methods for synthetic liners and on QA/QC for installation and jointing would also be valuable.

- It would also help to have data on mobility and persistence of various hazardous waste constituents. (The State has had problems with permittees, consultants, etc. that try to predict movement of materials in soils using water as the modeling fluid when the material involved is not water. For example, perchloroethylene at concentrations above the solubility move through soils at a rate far above water since the transport mechanism is entirely different.)

INTERVIEW NO. 6

Wehran Engineering:
666 East Main Street
Middletown, NY 10940

Robert D. Mutch, Jr.
Salvatore A. Arlotta
(914) 343-0660

MEESA:
Masood Ghassemi

11 November 1983

Summary

- The fundamentals of design for the bottom liners are esssentially the same for both landfills and surface impoundments. The design of side slopes for surface impoundments, however, has to take into account problems stemming from rapid drawdown, wave action and freezing-thawing of free water available to clay.

- The intragradient design, where the facility is intentionally located in the saturated zone, and the hydraulic barrier design, where an artificial piezometric pressure envelope is created between the primary and secondary liner, offer a number of advantages over conventional designs and would be specially suitable for surface impoundments. These designs provide a reverse hydraulic gradient against the liner, thus preventing outward migration of leachate or impounded liquids, even in the event of liner failure. Excellent results have been obtained in some large scale landfill applications of the intragradient principle.

- Minimizing potential for leachate formation (through use of properly designed and maintained caps) removing leachate from landfills, and designing liner systems complementing clay characteristics with FML (but not relying solely on the impermeability of FML) are three key elements of developing adequate facilities.

- Despite considerable improvements which have occurred over the recent past in leachate collection system design and construction, the apparent sporadic clogging of the underdrain systems remains a questionable area which must be addressed through research and development.

- Unless the construction steps are carefully supervised to assure adherence to design specifications, the adequacy of the completed facility cannot be guaranteed. This underscores the importance of good coordination, inspection and certification as key elelements of the QA/QC program.

Background

Wehran Engineering is a leading waste managememt company specializing in the design of land disposal faciliites for hazardous and non-hazardous wastes. The company has been responsible for the development of more than 200 waste disposal projects and is a pioneer and strong advocate of the intragradient landfill design as a protective mechanism for ground water resources. The company holds a patent on its hydraulic barrier concept for landfills or surface impoundments. Most of the Wehran's Projects have been in the East (particularly the industrial Northeast) and include some very large commercial hazardous waste disposal facilities. Tapping the extensive "real world" experience of a leading land disposal engineering company and obtaining its perspectives on key design problems and mitigation measures and R&D needs were the primary reasons for the interview with Wehran.

General Design Philosophy and Considerations

- There are no significant differences between the design of the bottom liners for landfills or surface impoundments. The design of the side slopes, however, has to address certain considerations which are unique to surface impoundments. These considerations include rapid drawdown and surface fluctuations, wave action, and freezing and thawing of the free water available to clay. These conditions, however, can be adequately mitigated through proper design, construction and operating procedures (e.g., use of rip-rap or filter protection and avoiding rapid drawdowns during operation).

- Most of Wehran's designs use a combination of FML and clay for liners thereby taking advantage of the desirable properties of both liner types and compensating for the possible shortcomings of the individual systems. In all cases, however, the design calculations rely solely on clay as the protector assuming that the FML would not be available as a back-up system. The clay-only liners will be used at locations where waste characteristics and hydrogeological conditions are suitable; FML-only liners, however, are not considered adequate for hazardous waste and will not be used by Wehran if there is liner-waste incompatibility and the commonly encountered installation problems.

- A good landfill design would ensure "dryness" via adequate provisions for leachate removal and control of leachate formation through the use of properly designed, constructed and maintained caps. Thus, in this regard, the impermeability of the liner and its leachate containment capability are not relied upon entirely in developing adequate facilities. To minimize the amount of precipitation entering a landfill, one commercial hazardous waste management company is planninng to use a temporary portable roof over a landfill during its construction and active life.

- The concept of designing and operating landfills as "reaction vessels" whereby leachate formation and stabilization are intentionally promoted during the early life of the site (when the liner, in particular the

FML, is still very new and presumably better capable of resisting the high strength leachate) might have some application to municipal landfills but not to hazardous waste landfills. Wastes placed in hazardous waste sites do not readily biodegrade and hence are not subject to rapid stabilization. Because of scheduling problems (at least in large commercial sites) it is difficult to arrange for co-disposal of certain wastes in the same cells as to achieve neutralization or controlled reactions.

- While real landfill leachate is very low in organic content and should not present incompatability problems for the liner, there are nevertheless instances where the liner may come in contact with slugs of concentrated waste (e.g., from a leaking drum). Thus, waste-liner compatibility tests in which pure solvents have been used as the test liquid can conceivably represent these worst case scenarios.

- The intragradient landfill design and hydraulic barrier concept which are actively promoted by Wehran (and which are briefly described at the end of this report) are attempts at addressing some of the landfill and surface impoundment design problems and providing for maximum ground water protection.

Leachate Collection System

- The plugging of the underdrain system by waste/leachate and not necessarily the occasional physical damage to the piping system which might occur during construction is the major cause of the apparent leachate collection system failure. (Even if a line is damaged, there are sufficient number of additional gravel void space and laterals through which the leachate can flow).

- The development of an improved leachate collection system which would be less susceptable to plugging than the current systems is an area of considerable importance and hence requiring research and development attention. Wehran has considerably and progressively advanced their design of the leachate collection systems as a result of the operating experience from a range of designs which they have employed. In the newer designs, Wehran uses 4-ft diameter man-holes which allow easier access to the piping system for cleaning and repair purposes. At the present time, however, there is no practical corrective measure for restoring the hydraulic capacity of a system when the sand and gravel drainage system is plugged.

- Although Wehran has accumulated considerable experience in leachate collection system design, much of the experience is considered to be confidential and not releasable without permission of their clients.

Importance of Construction and QA/QC

- Even with the soundest design, the adequacy of a completed facility cannot be guaranteed without assurance that the construction has been carried out per specifications. This underlines the importance of an effective construction QA/QC program.

- The QA/QC for FML should not only address the installation step but all preceding steps, including material selection, manufacturing, fabrication, transportation to site, etc.

- For FMLs, Wehran prefers to do much of the field seaming under controlled conditions by fabricating larger sections under favorable conditions (e.g., inside a building or warehouse.)

- Use of a very competent inspector is the cornerstone of an effective QA/QC program. Other elements of such a program include requirements for adequate record keeping and use of sign-off sheets and acceptance records.

- Wehran usually will have its own inspector on the construction site. For example, it will have a geologist at the borrow pit to flag any problem which might be detected during excavation. Extensive testing (density, permeability, etc.) is also done on samples of soil from the liner during construction. The contractor is required to construct a test patch before starting production work using the equipment and techniques which are to be used on the full-scale job. Only when the test section meets the required specifications, the contractor is allowed to proceed with the job.

- Cracking of clay is a highly site-specific problem which depends on the type of clay and its silt content as well as the moisture level and construction technique. Wehran's experience indicates cases where there have been only minor cracks even after one year of liner installation. In other cases, extensive cracks have been noted within a month of construction. Since a liner is constructed in lifts and there is little chance for alignment of cracks in adjacent lifts, a limited number of shallow cracks should not present a major leakage problem.

Research and Development Needs

- The intragradient design for landfills and surface impoundments should be further investigated and its performance documented more elaborately.

- The hydraulic barrier liner concept, which is considered especially suitable for surface impoundments, should be demonstrated in an actual application.

- New design concepts and construction techniques should be developed and evaluated.

- State and federal agencies should be made more cognizant of the importance of construction inspection, certification, acceptance procedures, etc. in developing an adequate facility.

Intragradient Design Concept*

- The intragradient design, depicted in Figure 27, has been developed as a conscious recognition of the inevitability of seepage through all liner materials, including geomembranes. The design calls for constructing the facility beneath the zone of saturation within low permeability geological strata. As long as the leachate in a landfill or the liquid level in a surface impoundment is maintained below the ground water table, there would exist a reverse hydraulic gradient which would promote a tendency for inflow of ground water and preclude outward migration of leachate or the impounded liquids. Since intragradient facilities are located in low permeability strata, the amount of ground water inflow is usually small and manageable, even in the event of complete liner failure.

- In addition to its leachate containment capability, the intragradient design would allow siting in many geological formations which because of their tight structures are ideal for waste disposal, but which have been heretofore excluded from consideration because they typically carry with them a high ground water table.

- The intragradient design has been successfully used by Wehran in a number of large scale facilities both for hazardous and nonhazardous waste disposal.

Example of a Successful Intragradient Installation

- SCA Chemical Waste Services, Model City, New York facility is a 900 acre hazardous waste treatment and disposal facility which has practiced secured land disposal since the late 1960s, beginning with Secure Landfill (SLF) Nos. 1 through 6. SLF No. 7, which was constructed in 1978, was developed as an intragradient landfill. It operated from 1979 to 1982. Subsequent to SLF No. 7, SLF No. 10 was designed, approved and constructed and is now in operation. It is also an intragradient landfill, as will be SLF No. 11 which is under state and federal review.

- The liner system for SLF No. 7 consists of a minimum of 5 ft of in situ clay (maximum permeability 1×10^{-7}cm/sec), overlain by 30 mil Hypalon liner with 10 x 10 scrim reinforcement, and covered with 2 ft of compacted clay (maximum permeability 1×10^{-7} cm/sec). The leachate collection system consists of a network of gravel-packed and perforated 8-in vitrified clay pipe. Reinforced concrete pipes are utilized as risers to permit entry of leachate pumping equipment. The landfill is divided into five cells for segregation of wastes. The leachate levels

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*The material on the intragradient and hydraulic barrier designs presented here has been excerpted from a draft paper entitled "Recent Advances in Secure Landfill Technology" by R. D. Mutch and M. R. Brother of Wehran Engineering.

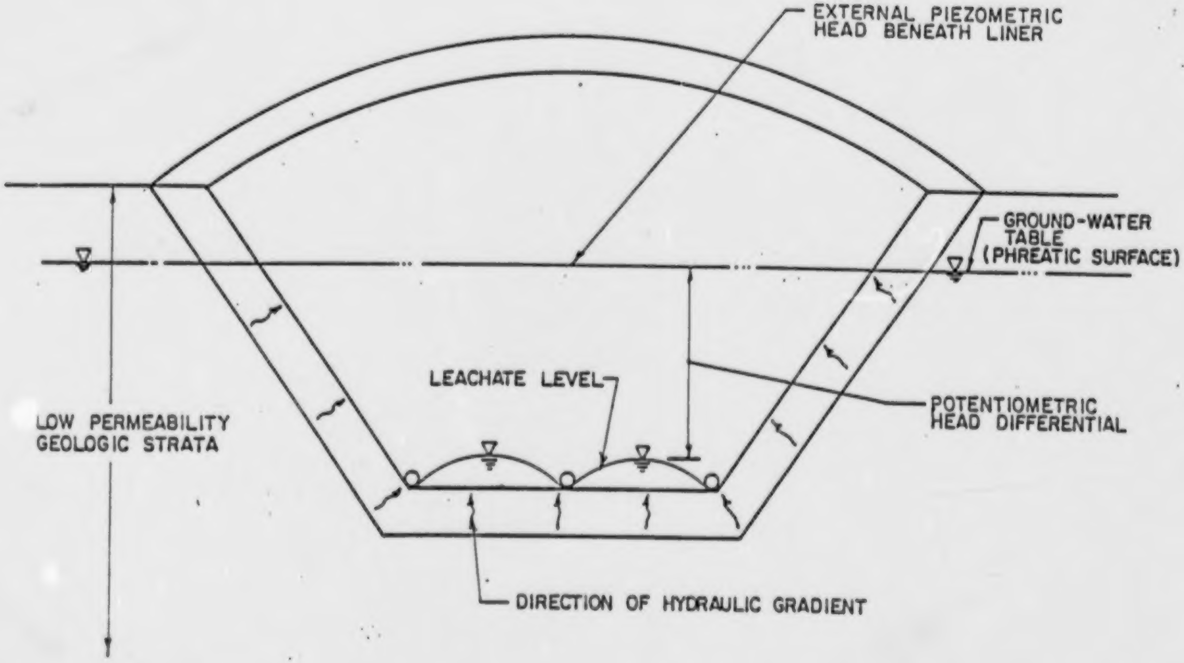
EXTERNAL PIEZOMETRIC HEAD BENEATH LINER
GROUND-WATER TABLE (PHREATIC SURFACE)
LEACHATE LEVEL
POTENTIOMETRIC HEAD DIFFERENTIAL
LOW PERMEABILITY GEOLOGIC STRATA
DIRECTION OF HYDRAULIC GRADIENT

Figure 27. Intragradient Landfill Concept

are maintained within 2 feet of the base of the landfills, well below the piezometric levels in the surrounding formations. Upon reaching final grade, the landfill was capped with an additional layer of compacted clay and a PVC geomembrane.

- SLF No. 7 began operations in 1979 and entered the post-closure period in late 1982. Throughout the operational and post-closure period, it had been maintained in an intragradient state. Leachate is withdrawn and treated on site in the facility's aqueous waste treatment system. There has been no discernable increase in leachate generation as a result of its intragradient design. Notwithstanding the facilty's intragradient design, the facility is extensively monitored. The monitoring has revealed no indication of leachate migration from landfill.

Hydraulic Barrier Design Concept

- Wehran Engineering has a patent (No. 4,335,978) on its hydraulic barrier concept for landfills or surface impoundments. The hydraulic barrier, or induced intragradient liner, design concept operates on the same principle as the intragradient landfill (i.e., the reversal of hydraulic gradient to preclude leakage from facility). It accomplishes this end by installation of a "piezometric pressure envelope" between a primary and secondary liner, as depicted in Figure 28.
- The hydraulic barrier concept thus overcomes the major limitation of the intragradient design, namely that of requiring a particular blend of hydrogeological conditions (i.e., high water table and impermeable formation) and can be used in most locations.
- The piezometric pressure envelope can be no more sophisticated than a conventional leak detection system. Except that, rather than maintaining it in an unsaturated state to detect leakage, the sand is charged with water from an external source to create a high pressure envelope around the primary liner. As long as the envelope's piezometric level exceeds leachate level in landfills or the level in surface impoundments, liquid migration from landfill or lagoon is precluded. The low permeability of liner would minimize the rate of inward water flow due to the reverse hydraulic gradient.
- The piezometric pressure envelope could conceivably consist of sand, gravel, or any material capable of transmitting peizometric head and possessing structural stability. A network of perforated pipes could be used to further assure dissemination of piezometric pressures throughout the pressure envelope. Geotextiles or geomembranes could be placed beneath and above the pressure envelope to minimize the intrusion of soil fines from compacted clay liners into the permeable medium.
- The control functions which would be incorporated in the design of the hydraulic barrier systems will allow for: (a) monitoring of piezometric levels and sampling of water from throughout the pressure envelope,

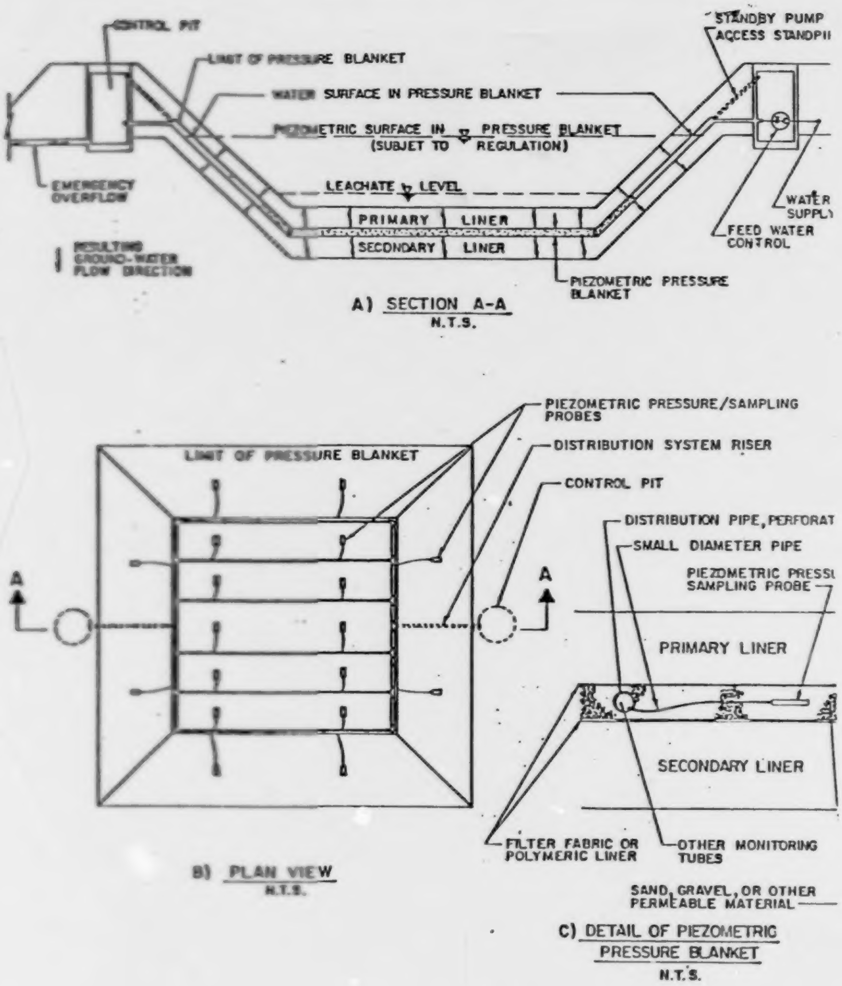
CONTROL PIT
LIMIT OF PRESSURE BLANKET
WATER SURFACE IN PRESSURE BLANKET
PIEZOMETRIC SURFACE IN PRESSURE BLANKET (SUBJET TO REGULATION)
STANDBY PUMP ACCESS STANDPII
EMERGENCY OVERFLOW
LEACHATE LEVEL
PRIMARY LINER
SECONDARY LINER
WATER SUPPLY
FEED WATER CONTROL
RESULTING GROUND-WATER FLOW DIRECTION
PIEZOMETRIC PRESSURE BLANKET
A) SECTION A-A
N.T.S.
PIEZOMETRIC PRESSURE/SAMPLING PROBES
DISTRIBUTION SYSTEM RISER
CONTROL PIT
LIMIT OF PRESSURE BLANKET
A
A
DISTRIBUTION PIPE, PERFORAT
SMALL DIAMETER PIPE
PIEZOMETRIC PRESSU SAMPLING PROBE
PRIMARY LINER
SECONDARY LINER
FILTER FABRIC OR POLYMERIC LINER
OTHER MONITORING TUBES
SAND, GRAVEL, OR OTHER PERMEABLE MATERIAL
B) PLAN VIEW
N.T.S.
C) DETAIL OF PIEZOMETRIC PRESSURE BLANKET
N.T.S.

Figure 28. Conceptual Details of the Hydraulic Barrier Liner

(b) measurement of the required water flow to the envelope, (c) emergency overflow in the event of the automatic piezometric head control malfunction or excessive water input to the system, and (d) large-scale withdrawal of water from the system.

- A unique aspect of the hydraulic barrier system is that it allows continual monitoring of liner integrity through routine measurements of the permeability of both the primary and secondary liner throughout the life of the facility. This can be done by recording the amount of feed water supplied to the envelope to maintain a particular piezometric head (a level coinciding with the liquid level in the facility for calculating permeability of the secondary liner, and above the liquid level for calculating the permeability of the primary liner).

- Wehran is currently exploring the funding possibilities for demonstrating the hydraulic barrier concept in a large-scale facility.

INTERVIEW NO. 7

Moore & Tabor:
Consulting Engineers
and Geologists
4530 E. La Palma Ave.
Anaheim, CA 92807

Mr. Return F. Moore
Mr. Don W. Clark
(714) 779-2591

MEESA:
Michael Haro

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Summary

- Geotechnical support should be a continuous effort covering site investigation through facility design and construction. It is especially important during pond and borrow pit excavation when major changes in soil properties must be detected and appropriate modifications made to the original design and the construction specifications.

- Because clay soils are difficult to handle, spread, mix, place on slopes, etc., formulation of detailed specifications for handling clay material and the use of an experienced and knowledgable construction contractor are essential in obtaining the best possible representation of the designed facility.

- Laboratory tests to assess clay suitability as a liner material and to develop basis for design and construction should utilize conditions closely resembling those expected in the field.

- Since construction specifications generally specify processing procedures along with required moisture content and density, it is the responsibility of the geotechnical consultant to ensure that the density and moisture levels attained in the field are indeed consistent with the permeability goals, per laboratory correlation tests.

- Subdrain leak detection systems offer several advantages over monitoring wells or use of indirect methods, including monitoring of a proportionately larger area of the pond, timely problem detection, and greater reliability of results.

- Proper initial conditioning ("curing") of the clay is equally important as maintaining proper soil conditions during clay liner placement operations. Moisture and density requirements can conceivably be satisfied, yet the liner may be inadequate because the clay layer may not be homogeneous.

- Areas in need of additional research relate to migration of contaminants in partially saturated soils and development of more reliable laboratory procedures and practical field methods for permeability testing.

Background

Since its inception in 1954, Moore & Tabor has provided geotechnical engineering, geological, and geophysical services to engineers, architects, governmental agencies, developers, contractors, and others. These services include the provision of data and recommendations for engineering projects such as industrial facilities, dams, tanks, reservoirs, sewage treatment plants, subsurface conduits, and placement of compacted fills. All of Moore & Tabor's projects have been in California and include some very large solid and hazardous waste disposal facilities and more than 150 earthen dams and reservoirs. Drawing upon the extensive experience of a leading geotechnical engineering firm and obtaining its geotechnical perspectives on key design problems and mitigation measures were the primary reasons for this interview.

Geotechnical Support Studies for Site Selection and Design

- Although results of preliminary geotechnical investigations may be used by the owner in screening candidate sites, the geotechnical consultant is not normally involved in the actual site selection process. The consultant task is primarily one of assessing the suitability of a given site (already owned or acquired by the client) for a specific project.

- Geotechnical studies provide the basis for developing sound designs, for ensuring use of suitable construction materials and practices, for assessing seismic and other potential geologic hazards, and for developing appropriate monitoring systems. The depth and thoroughness of a geotechnical investigation would vary with the nature and size of a project, design concept (e.g., zero leakage* for surface impoundments), and applicable regulations.

- Geotechnical support is especially important during pond and borrow pit excavation when major changes in soil properties must be detected and appropriate modifications made to the original design and the recommended construction practice. Thus, if a more permeable soil than that predicted previously is encountered, the use of a thicker liner may be necessary to achieve the design service life. Ideally, the geotechnical consultant should write the soils-related construction specifications (e.g., for clay liners, foundations, etc.); however, because this is often too costly, especially for small projects, and because construction specifications also cover non-soil related aspects of the project (e.g., concrete structures, FMLs, etc.), these specifications are usually written by the design engineering firm or owner. Continuous inspection of the excavation areas should be an element of the QA/QC plan and should be incorporated in the construction specifications.

- In line with the above consideration, the geotechnical consultant's views should be solicited in developing construction specifications and should be incorporated in such specifications. The geotechnical report should also be considered as a part of the specifications. Unexpected changes in soil properties which go undetected can result in structural and permeability problems which in turn can result in increased settlement and reduced pond service life, respectively. Because the design firm can misinterpret the soils specifications, the geotechnical consultant should have an opportunity to review and comment on the final specifications. In certain instances where the geotechnical consultant was not given opportunity to review and input construction specifications, problems later arose.

Evaluation of Clay Properties

- Testing of clay properties to assess its suitability as a liner material and to develop basis for design and construction should utilize conditions which closely resemble those expected in the field. Thus for hazardous waste ponds, permeability tests should utilize actual waste and should be conducted under hydraulic gradients expected in the field. These tests should provide data on changes in permeability over time, and evaluate density and moisture conditioning/compactive effort requirements to ensure compliance with design permeability.

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*Zero leakage refers to the service life of a clay-lined impoundment defined as the time necessary for retained fluids to migrate through the bottom of the clay liner and be detected by the leak detection monitoring system.

- As a QA/QC tool, field permeability measurement is an impractical means for assessment of the adequacy of the construction techniques. The efficiency of the field operation is usually determined by measurement of density and moisture levels which have to be translated to permeability values using correlation curves developed in the laboratory for permeability versus moisture content/density.

- Since some clays will expand when not confined, thus gradually losing density and hence permeability, changes in permeability over time versus density is an important clay property. Such data are used in the development of clay conditioning and placement specifications. For clays with permeabilities $<10^{-8}$ cm/sec, high differential pressure (i.e., running test with high head) must be placed on the sample to obtain results in a reasonable time period (10 days to 2 weeks). The major problem with this type of test, however, is in sealing the edges of the chamber (holding the specimen so that the clay will not deform).

Construction of Clay Liners

- From a construction standpoint, clay soils are difficult to handle, spread, mix with water, place on slopes, and compact properly. Development of detailed specifications for handling the clay liner material and the use of an experienced and knowledgeable construction contractor are thus essential for obtaining the best possible representation of the impoundment as designed.

- Moisture conditioning and curing of clay are very critical. In arid climates, excess water must be added and the clay allowed to cure (i.e., attain a uniform moisture distribution) for about 10 to 15 days (depending on the clay type). To ensure proper curing, it is important that during the curing period the moisture level be closely controlled (i.e., more water added or moisture allowed to evaporate). Compaction of the clay in the field should be carried out with a moisture content significantly above optimum (110% to 120% of the optimum).

- Since construction contractors generally follow the specifications, which are in terms of the desired moisture content and density, it is the responsibility of the design firm to ensure that the density and moisture levels attained in the field are indeed consistent with the permeability goal per laboratory correlation tests.

Leak Detection Systems

- Subdrain leak detectors, which permit direct observation, have merits over monitoring wells or use of indirect methods (e.g., thermistor or resistivity devices); the advantages include: (1) rapid detection and timely warning of failure (e.g., in contrast to monitoring wells that detect leakage too late for proper corrective action), (2) ability to monitor a relatively large area under the liner ($\sim$2% of the bottom) and not small areas around the perimeter, as with some indirect methods, and (3) yielding more reliable results than systems such as thermistors and resistivity devices which have not yet been fully tested in the field. Detection of fluid in the subdrain system can be interpreted to indicate the end of the service life for the facility.

- One limitation of the subdrain detection system is that certain site conditions such as a high water table may limit the system usefulness.

- The use of a single liner and subdrain system can eliminate the need for a double liner system if it is stipulated that pond operation will be terminated upon detection of fluid in the underdrain. Such a provision may not be applicable to large double lined facilities because of the difficulty of draining any non-waste related fluids which may accumulate in the system (e.g., seepage from surface run-off).

Clay Versus FML

- Well designed and constructed clay liners are more reliable than FMLs because there is no historical record of the performance of FMLs with various wastes and disposal methods. Inadequate seaming techniques is probably the biggest problem with FMLs.

- When clay is available on-site, clay liner would be considerably less costly than FML.

Research and Development Needs

- There is a need for studies of the migration of fluids and attenuation of pollutants in partially saturated soils. Because of the lack of data in this area, current regulations are overly conservative in limiting the life of a surface impoundment to the time that it would take for the liquid to exit the bottom of the liner. In areas with low water tables, 5 to 10 foot zones beneath the liner would add extra life to the pond.

- R&D effort should address development of laboratory procedures and practical field methods for permeability determination. (Large field permeameters are not practical for clay soils with permeabilities $\leq 10^{-8}$ cm.)

INTERVIEW NO. 8

IT Corporation 336 W. Anaheim Street Wilmington, CA 90744	David Bauer (213) 830-1781	MEESA: Masood Ghassemi Michael Haro

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Summary

- Because of their more temporary nature, there is generally more design flexibility with surface impoundments than with landfills. Problems with liquid level fluctuations and wave action associated with surface impoundments can be mitigated through proper design.

- The preference expressed in the proposed regulations for use of FML over clay as a liner material appears to stem largely from policitcal rather than technical considerations. FML is preferred because from a theoretical standpoint it would appear nearly impermeable compared to clay for which there is a definite leakage rate. This theoretical consideration, however, disregards the extensive documentation of poor FML performance in full-scale installations.

- The proposed California hazardous waste regulations would require double lining and use of FML in addition to siting in "Class I areas" for hazardous waste facilities. There is little technical justification for double lining and use FML in Class I areas which are geologically suitable for waste containment.

- Since once promulgated the regulations are binding, and beca[illegible] regulatory reform and repeal processes are slow, it is imperative that the regulations be originally sound and based on good science and technically defensible rationales.

- FML's most suitable place in land disposal application is in cover systems. With suitable designs FMLs can perform very satisfactorily in such an application.

- The problem with desiccation cracking of clay liners during construction is a minor and a manageable one.

- Construction supervision and detailed and documented verification inspection are most esssential in developing adequate facilities. Thoroughness, conscientiousness and experience are desired qualifications for a field inspector.

- In selecting an FML installer, the company qualifications should be judged in terms of its resident and available talents rather than only the past performance records, as individuals (particularly the foreman

- Areas requiring the greatest research and development attention include: (a) development of practical means for early detection of facility failures and for corrective measures, (b) establishment of criteria for design of ground water monitoring systems, (c) documentation of performance of large scale facilities (failures as well as successes), (d) review of the applicable experience from parallel disciplines (e.g., dam and reservoir construction), and (e) identification of design, construction and operating practices most conducive to trouble-free operation of the leachate collection systems for landfills.

Background

IT Corporation is a leading commercial waste management company which owns and operates hazardous waste landfills and surface impoundments in California and in several other states. Mr. David Bauer, IT's Vice President for Environmental Affairs has extensive "real world" experience with and has been intimately involved in the design, construction and operation of land disposal facilities for hazardous waste management. The objective of the interview was to obtain IT's perspective on critical factors and practical considerations in developing adequate surface impoundments and landfills and on key problem areas, mitigation measures and research and development needs.

Surface Impoundments vs. Landfills

- Since a good landfill design calls for a "dry" operation (i.e., not accepting liquid wastes and removing the leachate from the facility), an oversimplification of the difference between a landfill and a surface impoundment from a design standpoint is that one involves containment of liquids while the other involves containment of solids.

- Because surface impoundments are generally viewed as temporary structures and hence more amenable to corrective measures, there is considerably more flexibility in designing surface impoundments than landfills.

- The design and construction of sidewalls for surface impoundments have to take into account erosion and wind/wave actions which are absent in landfills. Use of rip-raps and shallower slopes can mitigate these surface impoundment-specific problems.

- The problem with odors is a major factor in siting and operating surface impoundments. Source control (i.e. not accepting odorous wastes or wastes which would react to produce malodorous compounds) remains the most effective operating method for controlling odors.

Clay vs. FML as Liner Material

- IT Corporation has exclusively used clay as a liner material for its land disposal facilities in the past. The company continues to have a strong preference for clay over FML, although it recognizes that it may have to use FMLs, at least in its California facilities, if the proposed California hazardous waste regulations (see Section on Regulatory Considerations, below) become finalized.

- Clay has been IT's liner of choice primarily because (a) it can be placed in very thick layers, (b) it offers a capacity to absorb waste and attenuate pollutant migration, and (c) there is considerable experience and professional knowledge with use of clay in engineering projects.

- The reason that regulations and regulatory agencies have indicated a preference for FML over clay is primarily one of political expediency rather than technical considerations. Even the best clay (e.g., permeability of 5 x 10^{-8} cm/sec) has a certain leakage rate associated with it. From a purely theoretical viewpoint FLM is nearly impermeable (e.g., permeability of 10^{-30} cm/sec or less) and thus on the surface would appear superior to clay. This kind of comparision, however, is invalid as it ignores the wealth of experience from large scale facilities which indicate that it is not possible to install synthetic liners which will not leak.

  To illustrate the problem, consider a full scale facility which is lined with 2 ft of clay having a permeability of 10^{-7} cm/sec. While there would be no seepage through clay during the first 2 to 3 years, liquid would gradually penetrate and break through the liner. Within the next 3 to 5 years there would be a gradual increase in the leakage volume (which would be reported as such to the regulatory/permitting agencies) until a constant leakage rate becomes established. With FMLs, on the other hand, and again from a purely hypothetical viewpoint, a plot of leakage rate vs. time should remain flat and should indicate an immeasurable amount of leakage (if any). The shape of this theoretical leakage rate curve for FML appears to be the basis for the expressed regulatory preference for this liner material. This curve, however, is an incorrect representation of the actual conditions which can entail a significant leakage stemming from bad seams, liner punctures, exposure damage, etc. Moreover, what is not addressed in regulations which prescribe FMLs is how to remedy liner failures which would surface after the facility (especially a landfill) is placed in service.

- It is recognized that certain wastes are not compatible with clay, but this is also true with certain FMLs. Waste segregation, pretreatment and banning disposal of certain troublesome wastes, however, would be effective mitigation measures for waste-liner incompatibility problems.

- Based on IT's experience, cracking is not a major problem with clay liners. Liners are placed in lifts and the chances that cracks in adjacent layers would line up in exactly the same areas is small. As long as the work is done at a reasonable pace, attention is paid to maintaining proper moisture content, and lifts are inspected for cracks and remedied, cracks should not be a major problem with clay liners.

- IT considers proper siting the best protection for ground water, independent of whether the facility is lined with clay or FML.

Use of FML as Cover Material and Related Design Considerations

- FML has proved to be effective in cover systems, and in this respect it has a definite place in waste disposal applications. IT has successfully used FML covers in two facilities. The cover in these facilities were installed 4 and 6 years ago and there has been no problem with erosion or slippage of soil cover, or failure due to differential settlement. In one of the facilities, the cover installation consisted of initial soil compaction, placement of a heavy (25-mil) polyethylene sheet, and placement of the soil cover. Natural vegetation growth has occurred in the soil cover at both sites. IT's maintenance philosophy on both these sites has been to "keep an eye on them, but leave them alone".

- IT's experience indicates that a slope of less than 3-5% and provisions to intercept and divert runoff from adjacent areas are critical to good cover maintenance.

Leachate and Gas Collection Systems

- While IT is aware of some of the problems which have been encountered in the facilities with the leachate and gas collection systems, the company itself has not experienced such problems at its facilities.

- Proper design and source control would be very effective in minimizing the potential for clogging of the leachate collection systems.

QA/QC Considerations

- Based on IT's experience, construction supervision and detailed inspection to verify adherence to design and construction specifications are most essential in developing adequate facilities. Inadequate construction inspection and verification are believed to have also been responsible for the failure of certain major engineering projects such as the Teton Dam where deviations from specifications were not identified in the inspection. In this case, the specifications called for using clay from a different source for each lift. This, however, was not done and was not identified in any inspection reports.

- Although IT has excellent in-house capabilities for writing construction specifications and for carrying out field inspections, as a matter of policy it almost always uses third parties for these tasks. Thoroughness, conscientiousness and experience are the most desired qualifications for a field inspector.

- In selecting contractors, IT often by-passes the standard bidding procedure and directly hires a reputable contractor which has had a good track record in the past.

- IT has had both good and bad experience with FML installers. This experience indicates that the installer's qualifications should be evaluated in terms of the resident and available talents and not of the jobs completed previously, as some of the employees responsible for past performance may no longer be with the company or not be available for the proposed job. These individual qualifications are especially critical for foremen and supervisors who are most instrumental in ensuring successful FML installation. Also critical in FML installation is the previous experience of the individuals with the particular type of liner which is to be installed.

- Supervising clay liner construction to ensure maintenance of proper moisture content is essential to developing an adequate liner. Maintaining proper moisture content, however, may be difficult under adverse weather conditions (e.g., prolonged wet periods) and this often requires exercise of good and on-the-spot judgement by the supervisory personnel. On one particular job involving construction of clay berm foundation and keying it to the bottom liner, because of prolonged bad weather conditions, IT chose to use a slurry wall and get the project completed rather than wait for improvements in weather conditions.

- Major surface impoundment and landfill jobs are usually done by very reputable companies and also receive considerable public scrutiny. Because of their high visibility and the reputation of the companies involved, these projects generally incorporate comprehensive QA/QC programs covering all steps leading to the development of a completed installation. Cases of failure attributed to inadequate QA/QC, however, are more prevalent among the more numerous and scattered smaller jobs which are done by less reputable, smaller companies. It is these installations which in totality present a much greater environmental threat than the much fewer, larger well-built facilities. This consideration underlines the danger in any relaxation or wavering of the liability insurance requirements for jobs done by small business, as has been proposed and is now being actively pursued by certain interest groups.

Geotechnical and Other Technical Considerations

- The State of Colorado has used an excellent approach to assist facility developers and regulatory agencies in their geotechnical investigations for disposal facility siting and other activities impacting ground water and soil resources. Geological survey maps of the state have been used to identify suitable geological areas for "Class I" waste disposal (i.e., areas under which there is no usable ground water and underlain with at least 1000 ft of shale). These maps serve as initial guides in site screening. It is the responsibility of the owner/operator to verify conditions at a particular site(s) when the selection is narrowed. Although the Colorado's approach may not be directly applicable to other states (e.g., California), the concept is of considerable merit and a valuable service to regulatory agencies and waste disposal facility owners/operators.

- For its Imperial Valley site in California, IT relied on the results of the state geotechnical studies of the area to select the most suitable geology. Additional geotechnical studies were then conducted to narrow the selection. IT's experience at this site and at other locations indicates that there is often a tendency to underestimate the extent of geotechnical efforts required in selecting a suitable site.

- In cases where more than one disposal technology is utilized at a site, the requirements for and the extent of monitoring of individual technologies would depend to a large extent on the site conditions. In general 3 to 4 times as many monitoring wells might be required to document the performance of individual technologies in multiple source situations.

Regulatory Considerations

- IT operation in California would be most significantly impacted if the proposed state hazardous waste regulations are promulgated (the current regulatory time table calls for finalization of regulations by April 1984). The proposed regulations (revisions to Subchapter 15, Chapter 3, Title 23 of the California Administrative Code) appear to be one of most restrictive of the regulations proposed by various states. The California regulations call for use of FML in addition to clay in order to comply with the interim federal RCRA regulations per 40CFR 264.221(a), 251(a) and 301(a1)(1). This requirement for double lining and the use of FML is in addition to the siting requirement which calls for locating hazardous waste disposal sites in "Class I" areas. A Class I area is defined as one providing "the optimum geological conditions for hazardous waste isolation, including natural geological barriers capable of preventing vertical waste movement from a waste management area to waters of the state".

- Except for an apparent purpose of conforming to RCRA July 1982 Interim Final Regulations so that the state would receive authorization for Phase II regulations, there appears to be little technical justification for the unnecessarily restrictive proposed California regulations. The requirements for siting in "Class I" areas, double lining and use of FML constitute an "overkill" which entails unjustifiable additional costs. Again, the basis for the proposed regulations appears to involve political considerations rather than use of sound reasoning and good science. There appears to be no justification for a requirement to retrofit existing facilities which are located in Class I areas and which have a documented record of good performance.

- Recognizing that once promulgated the regulations are binding and that the reform or repeal of regulations is an extremely slow and lengthy process, it is imperative that regulations be based on good science and sound engineering.
- A major contributor to the inadequacies of some of the regulations which have been heretofore promulgated is the inability of the regulatory agencies to attract and retain experienced personnel. The problem is compounded by the political considerations which often partially or totally replace technical considerations in the regulatory decision making process. Also, there has always been the problem of a lack of full coordination among various regulatory agencies with overlapping responsibilities (e.g.,in the case of California between the State Water Resources Control Board and the Department of Health Services).

Research and Development Needs

- There are currently a large number of landfill facilities in the country which are located over usable ground water. Some of these facilities have failed and have contaminated, or present a contamination threat to, the ground water resource. The current situation underlines the need for developing protocols for early detection of site failures and corrective measure procedures. New failure detection systems which have been proposed (e.g., using resistivity and accoustical measurements) must be tested under actual and "real world" conditions. Presently, we generally learn of a site failure only after the ground water is contaminated (e.g., pollutants have been detected in water wells outside the facility boundary). The national ground water monitoring programs have also been inadequate in that the individual monitoring efforts have not been tailored to site-and waste-specific conditions (e.g., detection of contaminant species expected from a given facility).
- There is a substantial need for developing a technical basis for proper design of ground water monitoring systems (e.g., addressing the optimum number and location of monitoring wells). IT has used a cluster well system (i.e., several wells in the same general location, but extending to different depths) at one of its facilities. This approach, however, has not been well received by some regulatory agencies who apparently find it difficult to process and interpret the large volume of the monitoring data produced with such systems.
- Case studies documenting the operation of full scale facilities (successes as well as failures) can yield valuable lessons and contribute to the development of better design, construction and operation of land disposal facilities.

- Effort should be undertaken to collect the wealth of experience which exist in parallel disciplines and projects (e.g., construction of dams and reservoirs) and to assess their applicability to the design and construction of waste disposal sites. Even in the waste disposal field there is a considerable amount of accumulated experience (e.g., as to the optimum lift thickness vs. construction equipment and clay characteristics in liner construction) which needs to be collected, analyzed and disseminated to practicing engineers and regulatory agencies.
- Identification of proper design, construction and operating practices which would minimize the potential for clogging of leachate collection systems for landfills, and development of corrective actions for clogged systems require considerable research and development attention.

INTERVIEW NO. 9

State of California

Water Resources Control Board:
P.O. Box 100
Sacramento, CA 95801

Robert S. Ford
(916) 322-0844
Bud Eagle
Eric Findlay
Charlene Herbst
Jim Parsons
Jim Strandberg
Gil Torres

MEESA:
Masood Ghassemi
Michael Haro

Dept. of Health Services:
714 P Street
Sacramento, CA 95814

Elgar Stephens

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Summary

- The proposed California hazardous waste management regulations are intentionally very stringent to provide an added factor of safety which is needed when one considers that (a) even some well designed facilities have failed, (b) clean-up costs are very high, (c) there is always a potential for waste migration, even under the best hydrogeological site conditions, and (d) it is necessary to protect the state waters not only for the present uses but also for potential future uses.
- The proposed regulations represent substantial revisions to existing regulations and include restructured waste categories, revised site classification criteria based primarily on hydrogeologic characteristics of each site, specific construction standards for containment and

drainage control, comprehensive monitoring provisions, and separate provisions for mining and non-hazardous wastes.

- The proposed regulations require the use of artificial liners in addition to siting in areas with at least 20 ft of natural material having a permeability of $\leq 1 \times 10^{-7}$ cm/sec. Based on experience, FML alone would not provide the long term durability of clay and the recommendation for its use is primarily in response to RCRA requirements.

- R&D effort should be derived at developing (a) practical and economic methods for determining waste-liner compatibility, (b) standard permeability tests using waste/leachate as permeating fluid, (c) reliable, maintenance-free, and retrofittable monitoring techniques for unsaturated zones, and (d) methods for evaluation of cover system designs for arid regions.

Background and Objective

The State Water Resources Control Board is working with the Department of Health Services to develop joint regulations for the safe handling, treatment, storage, and disposal of hazardous waste. The State of California has been a leader in environmental legislation and the proposed regulations go beyond the minimum federal requirements of RCRA in several respects. The proposed regulations have been criticized by some industrial concerns as somewhat unnecessarily overstringent.

The objectives of this interview were to get familiar with the technical data base for the proposed regulations and to obtain the state's perspective on various aspects of design, construction, operation, permitting, etc. of surface impoundments in California. Since the interview, the state has produced a "Statement of Reasons" document in support of the proposed regulations. Pertinent portions of this document are excerpted and presented as supplement to this interview report.

Impetus and Basis for Proposed Regulations

- The existing California hazardous waste regulations have been determined by state to lack clarity and, in some areas, to be inconsistent with federal statutes and other state health and safety codes. This determination, plus the need to address closure and post-closure maintenance requirements, led to a proposal to repeal the existing regulations and replace them with the proposed regulations which represent substantial reorganization and revisions of the existing regulations.

- The development of the proposed regulations has been guided by the following objectives:

  - Incorporation of a number of criteria presently contained in state guidelines for discharge of nonsewerable wastes to land

  - Conformance with RCRA requirements
  - Development of site classifications which would resolve technical and administrative problems associated with existing site classifications
  - Address management of wastes from mining, animal confinement facilities, and other non-RCRA wastes.
  - Conform with requirements of the California Administrative Procedures Act

- The technical basis for the proposed regulations are the current literature and discussions with environmental organizations, local governmental agencies, consultants and industry, as well as the state's many years of experience in regulating hazardous/industrial waste discharges. No specific background technical support document was prepared in connection with the development of the new regulations.

- As part of the development of the new regulations, an administrative decision was made that the Department of Health Services would be responsible for enforcement of construction standards for hazardous waste facilities whereas the State Water Resources Control Board would be responsible for geological siting and groundwater monitoring requirements.

Specific Requirements of the Proposed Regulations

- Siting Requirements —— Hazardous waste landfills impoundments, and waste piles (Class I waste management units) must be located: 1) outside the 100-year floodplain; 2) outside dam failure inundation areas; 3) 200 feet from known Holocene faults; 4) outside areas of potential rapid geologic change; 5) outside coastal/shoreline areas; 6) in continuous strata not less than 20 ft thick having a permeability $\leq 1\mathrm{x}10^{-7}$ cm/sec; 7) 5 ft above the highest anticipated elevation of the capillary fringe of underlying groundwater to minimize leachate generation; and 8) in areas having natural or artificial barriers to prevent lateral waste movement to water.

- Construction Standards —— The proposed standards, summarized in Table 39, call for the use of clay and synthetic liners, leachate collection systems (capable of handling twice the anticipated daily leachate volume), cut off wall/grouting curtains (where there is potential for lateral movement of waste or leachate), interim cover, drainage control and seismic design.

- Liner Inspection —— Inspection of surface impoundment liner is required once every two years. Unless reliable leak detection tests are developed (i.e., tests that can locate pinholes and small tears), liner inspection would be for detecting gross deterioration. Final regulations will require provisions for liquid storage while the pond is being inspected. The proposed regulations also require a 3-ft freeboard allowance for surface impoundments.

TABLE 39. SUMMARY OF CONSTRUCTION STANDARDS FOR WASTE MANAGEMENT UNITS

Type of Waste Management Unit	Clay Liner	Synthetic Liner	Leachate Collection and Removal System	Interim Cover	Subsurface Barriers		Capacity of Precipitation and Drainage Control Facilities	Seismic Design
					Cutoff Walls	Grout Curtains		
Landfill	required, 1×10^{-7} cm/sec$^{(1)}$	required$^{(4)}$	required, blanket type	required	1×10^{-7} cm/sec$^{(7)}$	1×10^{-7} cm/sec	probable maximum precipitation	withstand maximum credible earthquake
Surface Impoundment	double liner$^{(2)}$, 1×10^{-7} cm/sec	required$^{(5)}$	required, blanket type		1×10^{-7} cm/sec$^{(7)}$	1×10^{-7} cm/sec		
Waste Pile	optional$^{(3)}$ 1×10^{-7} cm/sec	not required$^{(6)}$	required, blanket type	required	1×10^{-7} cm/sec$^{(7)}$	1×10^{-7} cm/sec		

NOTES:

1. All permeabilities specified in this table are maximum allowable permeabilities.
2. Outermost layer of outer liner shall be clay; synthetic inner liner may be used in place of clay if inspected biennially.
3. A synthetic liner alone may be allowed based on nature of waste to be contained and duration of the operation. A waste pile with a synthetic liner alone may not be closed as a landfill pursuant to Section 2583 of Article 8. The synthetic liner permeability shall be the same as that which would be required for a clay liner.
4. Synthetic liner required in addition to clay in order to comply with 40 CFR 301(a)(1) unless exempted pursuant to 40 CFR 264.301(b).
5. Synthetic liner may be required to comply with 40 CFR 264.221(a) if inner liner of double system is not synthetic, if double clay liner system is not removed at closure per Section 2582(b)(1) of this subchapter, or if not exempted pursuant to 40 CFR 264.221(b).
6. Synthetic liner required to comply with 40 CFR 264.250(b) if waste pile is to be closed with wastes left in place.
7. Cutoff walls required where there is potential for lateral movement of waste or leachate.

- Groundwater Monitoring — Because groundwater monitoring systems historically have not been properly located or installed, the state does not know how well (or poorly) hazardous waste facilities in California are performing. Accordingly, the proposed monitoring requirements are very stringent and detailed and include requirements for monitoring the unsaturated (vadose) zone.

- New Versus Existing Facilities — Under the regulations as currently proposed, all requirements for new sites are also applicable to existing facilities "if possible" (i.e., it may not be possible to meet siting standards such as outside 100-year floodplain, construction specifications such as use of cutoff walls, and monitoring requirements such as monitoring of vadose zone).

- QA/QC Requirements — Although no specific QA/QC requirements have been included in the current version of the proposed regulations, the state recognizes the extreme importance of QA/QC and may incorporate such requirements in the regulations before they are finalized.

Justification for Apparent "Overstringency"

- The apparent "overstringency" of proposed regulations is based on the state's experience which indicates that (1) some well designed facilities which have used the state-of-the-art technologies have failed, (2) geologic formations are often discontinuous and the potential for lateral or vertical migration of wastes cannot be fully eliminated, and (3) when damage occurs, the cost of clean up can be very high. For example, a double-lined, apparently well designed surface impoundment in Porterville, CA failed recently. Over 50 priority pollutants have now been detected in the town's drinking water supply affecting some 200 homes. The pond design would readily pass the RCRA requirements and yet both pond liners failed without any warning from the leak detection system between the liners.

- The apparent "overstringency" of the proposed regulations also reflects the state's desires to protect potential future uses of some of the state waters which may now be considered "unusable". For example, a 10,000 mg/l TDS water may find some use in the future or technologies may be available in the future to economically produce usable water from such a brackish source.

Research and Development Needs

- There is a substantial need for developing practical and economic methods for determining liner-waste compatibility. The data from such tests can be used by (a) facility operators as the basis for keeping out incompatible wastes from operating landfills or surface impoundments, and (b) by design engineers in selecting suitable liners.

- Standard procedures/tests should be developed for evaluating permeability using actual waste/leachate (and not water only). In this connection studies must also be conducted to develop tools for predicting the characteristics of leachates resulting from landfilling of various waste types.

- Research should also be conducted on the effectiveness of various cover system designs in arid regions.

- R&D efforts should also focus on the development of reliable, maintenance-free, and retrofittable monitoring techniques for the unsaturated (vadose) zone.

Rationale for Specific Key Requirements in the Proposed California Hazardous Waste Regulations*

Siting Criteria

The requirement for Class I facilities ... are needed to enforce the highest standards practical regarding the disposal of hazardous waste. In the preamble to RCRA the EPA states that the purpose of their proposed regulations is to prevent leakage; but in actuality, the proposed federal regulations allowed limited leakage. Compliance monitoring and alternate concentration limit concept described in RCRA reflect this belief. State Board policy differs from this RCRA-expressed philosophy of limited degradation because, once beyond containment facilities, contaminants are difficult to contain or treat. Attempts to remedy water quality degradation are expensive and only partially successful. The geologic containment criteria provide long-term containment--to continue until wastes no longer pose a threat to water quality. In contrast, the RCRA philosophy assumes that at some point leakage will occur, but does not expect containment to last until wastes are no longer a threat. Requirements for natural and artificial barriers, along with the requirement for low permeability geologic materials, reflect reliance on geology to prevent hydraulic connection between any leakage and ground or surface water over long periods of time. The enhanced lateral containment from cutoff walls and slurry trenches will complete the natural containment features on site.

Control of leachate, once formed, is most difficult. Soluble waste constituents are made more mobile when dissolved in water. The increased mobility increases the possibility that waste constituents will escape the unit. Many of the siting requirements...are directed toward keeping non-liquid wastes as dry as possible. Siting and designing units to protect from flooding and other natural disasters also helps to protect those features at the unit which are to contain the waste.

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*Excerpted from the "Statement of Reasons" document which accompany the proposed regulations.

Geologic changes can impair the integrity of containment features. "Rapid" refers to the length of time over which the geologic change takes place relative to the length of time the wastes pose a threat to water quality.

Geologic changes may be landslides or other slope stability problems, sedimentation, erosion, settlement, rapid subsidence, or any other process that could threaten containment structures or restrict the ability of the site to contain waste.

Some features, such as landslides, may be inactive at the time of site development. It is intent of these regulations to preclude any waste disposal operation that would reactivate such a feature and threaten containment. Features such as ancient landslides shall be avoided since ancient landslides have an inherent potential for rapid change and natural conditions or waste disposal operations could reactivate such features and threaten containment structures.

Natural geologic material beneath a Class I waste management unit shall be as nearly impermeable as possible. Experience of staff indicates that 1×10^{-7} cm/sec is the lowest permeability which can be reliably measured in the field or laboratory. The surface impoundment standards for Class I units are more stringent than those specified in RCRA since low natural permeability has been required in addition to liners. There are two main reasons for these natural permeability requirements: 1) liners of hazardous waste surface impoundments are generally more susceptible to leakage because hazardous waste is more likely to attack liners; 2) if at some time liners eventually leak, the wastes which escape the facility should not be allowed to reach ground water. It is cheaper to require the best containment possible than to require cleanup.

No less than 20 feet of natural geologic material having a permeability of not more than 1×10^{-7} cm/sec is required to provide a backup to other artificial containment features. The 20 feet of material will provide a backup to the leachate collection and removal system in the event of failure of the system. The 20 feet shall provide a buffer in the event of a leak in the lining system or failure of other containment structures. If contamination moves into the soil and the soil needs to be removed, there will still remain a substantial thickness of naturally occurring geologic material of low permeability. Since the life of the waste material is often much longer than the active life of the facility, requiring 20 feet of low permeability material provides some insurance that there will be a barrier to contain the waste and to protect ground water quality after closure; this natural barrier will not require maintenance and inspection.

Artificial barriers are allowed to enhance natural, lateral, low permeability because: 1) lateral waste movement is easier to detect; 2) lateral barriers are easier to repair than barriers underlying the waste management unit; and 3) less pressure will be placed on lateral containment structures as compared to vertical containment structures.

Construction Standards

It is specified that permeability requirements given in the proposed regulations are relative to the waste and leachate to be contained. It is recognized that permeability rates of materials may differ depending on the composition of the substance used for testing. Organic solvents in particular can affect the ability of a material to contain wastes.

The regulations specify clay liners because operational experience has shown that synthetic liners do not have the long-term durability of clay liners. Based on staff's experience with synthetic liners, staff feels that clay is a better material for long-term containment ... Two feet of clay are specified for Class I ... waste management units to guarantee that an adequate thickness of clay is present throughout the waste management unit, since large-scale construction produces varying thicknesses of material throughout an area. A minimum relative compaction of 90 percent is specified to guarantee the structural integrity of the liner materials and prevent consolidation. This compacted material will provide a firm base for placement of the leachate collection system and the waste. The 90 percent standard must be met in addition to any permeability standard.

A minimum thickness of 30 mils has been specified for synthetic liners in keeping with the recommendation of the EPA Guidance Document.

All liners shall be installed to cover all natural geologic materials likely to be in contact with waste or leachate so that pollutants cannot move around the liner and so escape into ground or surface water.

The permeability value $1x10^{-7}$ cm/sec was chosen as the maximum allowable liner permeability because liners shall be as nearly impermeable as possible, so that containment will be as nearly absolute as possible. Because of difficulties with measurement, staff's experience is that $1x10^{-7}$ cm/sec is the lowest permeability which can be reliably measured in the field or laboratory. Permeability of $1x10^{-7}$ cm/sec or less is required for both liners in a double-lined surface impoundment because pressure from the weight of the waste will eventually cause the inner liner to leak. A slow rate of leakage is preferable so that leachate can be collected and removed without exceeding the capacity of the leachate collection system between the liners. Because some fluid will eventually be in the leachate collection system, the outer liner must be of low permeability as well, so as to prevent migration of waste through the liner and into the environment.

These regulations specify that precipitation and drainage control facilities at Class I waste management units be sized to the probable maximum precipitation (PMP) at the unit. PMP represents the best judgement of meteorologists of the realistic upper limit of precipitation that can occur at a given location. The procedure to determine the PMP has been developed for regions of little to moderate topographic variation and involves two steps: (1) the preparation of probable maximum depth-area-duration curves representative of the region under study, and (2) the selection by means of these curves of a pattern storm for use in the basin. The State estimates the probable maximum precipitation to be 15 standard deviations in excess of the mean value of precipitation for any particular climatological station.

The PMP is used for the precipitation and drainage control facilities at Class I facilities because it reflects the State Board's requirement that these facilities will have zero discharge to either surface or ground water.

The maximum credible earthquake, one which appears capable of occurring based on all known geologic facts, ... is a conservative design requirement, chosen because the threat of water quality impairment is great if containment features at Class I unit is damaged or destroyed. Also, significant earthquakes often occur on unknown faults. The possible effect of shaking from these unknown faults would not be considered when determining the maximum credible earthquake.

Leachate collection and removal systems are required to be sized to handle twice the maximum anticipated daily volume of leachate so as to provide a safety factor to compensate for the uncertainties of calculating the volumes of leachate to be produced. Daily volume was chosen for leachate collection and removal system sizing on the assumption that the systems will be inspected daily.

Freeboard and Liner Inspection for Surface Impoundments

Three feet of freeboard are specified to provide a margin of safety to prevent overflow under the greatest anticipated seasonal rainfall and associated wind conditions.

Biannual inspection of synthetic liners is required for several reasons: (1) synthetic liners are thinner than clay liners and more subject to puncture, tears, or other type of damage; (2) impoundments are accessible to visual inspection of the upper liner; and (3) liners for surface impoundments are in direct, continuous contact with waste.

Monitoring Requirements

Without unsaturated zone monitoring, pollution problems will not be detected until too late to provide effective corrective action. However, this regulation goes beyond (RCRA) in that unsaturated zone monitoring is required whenever practicable at Class I waste management areas because the State Board staff position is that unsaturated zone monitoring is an important tool for early detection of leakage. Both soil-core and soil-pore liquid monitoring are required for land treatment areas. These two monitoring procedures are intended to complement one another. Soil monitoring will provide information primarily on the movement of "slower-moving" hazardous constituents (such as heavy metals), whereas soil-pore liquid monitoring will provide essential data on the movement of fast-moving, highly soluble hazardous constituents that soil monitoring may have missed. Soil monitoring is not required at waste management areas other than land treatment areas because of difficulties in sampling once facilities are in place.

APPENDIX A

FACILITIES REVIEWED BUT REJECTED AS CASE STUDIES

FACILITY A

REASON FOR REJECTION AS A CASE STUDY

There are inadequate monitoring data to enable assessment of SI performance. The groundwater monitoring system has only been installed very recently (July 1982) and no other data are available to provide basis for performance evaluation.

GENERAL DESCRIPTION

This metallurgical process development facility consists of a research lab, analytical lab, pilot plant, wastewater surface impoundments, and an administration building. Their activity deals with the development of a nonpolluting hydro-metallurgical process for the conversion of copper sulfide concentrates to elemental copper. The patented process utilizes leaching, crystallization, and hydrogen reduction unit operations. The plant has about 50 employees and covers ten acres in a rural desert environment next to a river in the Southwest.

Waste from research analytical laboratories and pilot plant operations is discharged into a lined tailings pond for settling. Wastewater overflow from this pond is discharged to another lined pond directly to the south.

SI DESIGN AND OPERATION (See Figure 29)

Based on an inspection report, the two surface impoundments, about 1-1/2 to 2 acres each, have 30-mil reinforced Hypalon liners in good condition. The liners cover the insides and tops of the earthen dikes. Large rip-rap (rocks) was placed on the tops and outside slopes of the dikes in order to prevent erosion. The freeboard level is inspected daily and the dikes are inspected weekly by operations personnel. Three unlined ponds in the same general location as the lined ponds are now permanently closed.

The wastewater in the ponds is considered hazardous because of its corrosive characteristics (due to the presence of sulfuric acid) and its trace element content. The pond pH has an approximate value of 1.0.

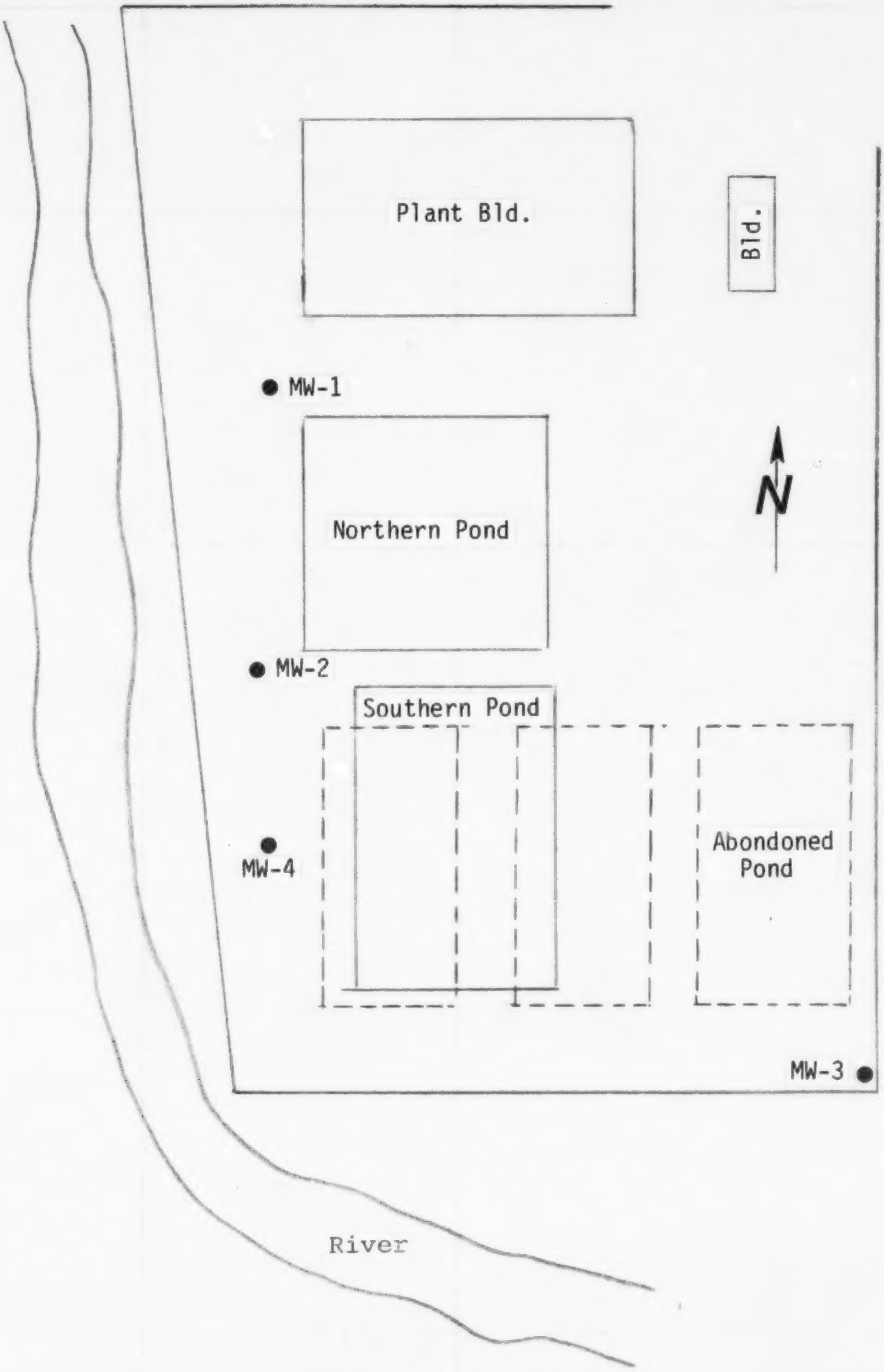
Plant Bld.
Bld.
MW-1
N
Northern Pond
MW-2
Southern Pond
MW-4
Abondoned Pond
MW-3
River

Figure 29. Plot Plan and Groundwater Wells for Facility A

SI PERFORMANCE

The facility has four groundwater monitoring wells in the vicinity of its two surface impoundments. The location of the wells relative to the impoundments are shown in Figure 29. The upgradient well is #3, approximately 400 feet southeast from the corner of the southern pond. Wells #1, 2, and 4 are probably hydraulically downgradient from the impoundments (flow towards the river). Placement of the wells was complicated by local geohydrology which indicated a perched water table in the area. The placement of the wells was reached in mutual agreement with state officials. These wells were properly cased and sealed.

FACILITY B

REASON FOR REJECTION AS A CASE STUDY

The wastewaters discharged to surface impoundments would not be classified as hazardous waste per definition in 40 CFR 264. The accumulation of fluid in the observation wells cannot be assumed to provide conclusive evidence for pond leakage due to nearby irrigation activities which can contribute to fluid accumulation.

GENERAL DESCRIPTION

This olive curing facility is located in an alluvial valley of the Southwest with a dry-summer subtropical climate. Brine curing wastewaters and olive process wastewaters are discharged to eight FML-lined evaporation ponds. Four of the ponds, with a total area of 45 acres, are located adjacent to the olive plant (the primary ponds). The remaining four ponds (the secondary ponds), with a total area of 95 acres, are located one mile west of the facility and receive waste via a pipeline. In addition to the primary and secondary ponds, there are about 15 acres of clay-lined ponds located immediately south of the plant. These ponds, which previously handled plant wastes, are now dry and no longer in service.

The soils in the area have fine sandy loam textures down to 60-inches. Compact, stratified zones below 5 feet tend to inhibit vertical movement and increase lateral flow. Groundwater depth in the area is about 100 feet and is of an excellent quality.

SI DESIGN AND OPERATION

The primary and secondary evaporation ponds are double-lined with 10-mil polyethylene sheets. These liners are separated by 2 feet of sand on the side slopes and 1 foot of sand on the bottom of each pond. The liners are sealed to inlet and overflow pipes; rip rap is placed around pipe appurtenances to prevent sloughing on slopes.

Presently, brine curing wastewaters are discharged to the primary and secondary evaporation ponds at a rate of 0.5 and 0.8 million gallons per day, respectively. This wastewater has the following characteristics:

Parameter	Range
pH	8.7 - 10.7
Conductivity (mhos)	6,000 - 68,000
Chlorides (mg/l)	1,400 - 24,000

SI PERFORMANCE

The ponds have a leak detection system which consists of shallow piezometer test wells around the perimeter. There are 5 test wells around the primary ponds and 20 wells around the secondary ponds. The test wells are monitored monthly to detect potential pond leakage. Soil borings around the ponds have verified the existence of hard pan at about 12 to 14 feet below the ground surface. The hard pan is a hard impervious layer of soil clay cemented by insoluble materials and serves as a bottom liner for the piezometer leak detection system.

From January 1980 to March 1983, no seepage has been detected in any of the piezometers of the primary ponds. However, during the same time period, water has been detected in a test well located at the southwest corner of the secondary ponds. Electrical conductivity of water from this well has ranged from 600 to 14,000 mhos. A state inspector has indicated that this test well is located adjacent to an irrigated field and is probably being affected by normal irrigation.

FACILITY C

REASON FOR REJECTION AS A CASE STUDY

Although the SIs have not been officially closed out pursuant to RCRA regulations, according to the owner* no hazardous wastes have been received by the site since new liners were installed in mid-1982, and the impoundments currently contain no hazardous liquids or solids. Although there is documented groundwater contamination, the contamination cannot be conclusively attributed to the SIs because of several other possible sources of contamination.

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*Letter received from the owner (dated 17 May 1983) declining request to participate in the study on grounds that he did not consider the site an active hazardous waste site and, hence, not a suitable case study candidate.

GENERAL DESCRIPTION

There are two FML-lined SIs on this 9.78-acre chemical and plastics manufacturing plant located in a heavily industrialized part of a major metropolitan area of the Southwest. The plant began operating in 1958; prior to this time, the facility had been a small oil refinery. From time of construction to 1982, the SIs were used for storage and ultimate disposal via evaporation of acidic and arsenic-bearing process wastes, as well as cooling tower blowdown, boiler blowdown and stormwater runoff from process areas. After 1982, operating procedures were modified and only rainwater runoff from building roofs and from cooling towers with no hazardous waste constituents were impounded. In addition to the SIs, there is an on-site surface storage tank for process sludges.

SI DESIGN AND OPERATION

Prior to 1974, there was one unlined 150' x 100' x 10' SI with a capacity of 530,000 gallons at the site. After the state questioned the adequacy of the pond, the SI was lined in 1974 with a butyl rubber liner. Due to periodic overflows of the pond stemming from inadequate sizing and curbing, in 1977 a second 150' x 150' x 10' butyl rubber lined SI was constructed adjacent to the first SI to handle overflow. No special foundation preparation was utilized prior to placement of the original liners other than grading of the pond bottoms.

In 1982, inspections by state regulatory personnel revealed the presence of numerous tears, both above and below the liquid levels in both ponds. Damage was presumably due to sunlight/uv oxidation. Both ponds were subsequently relined by placing 45-mil Hypalon reinforced liners on top of the old liners.

Waste is pumped to the SIs via pipeline. There are no outlets, since the SIs serve as evaporation ponds.

SI PERFORMANCE

Groundwater contamination was detected at the site during a sampling and analysis program involving 15 shallow monitoring wells installed on-site in May 1980. However, because of multiple past and present possible sources of contamination (e.g., large oil and process waste spills by the previous site owner, possible leakage of the original unlined SI, and periodic overflow of the first SI before construction of the second SI), the exact source of the pollution cannot be ascertained. The groundwater monitoring program indicated that significant concentrations of As, Pb, Cl, P, and depressed pH were present in 9 of the 15 monitoring wells. Groundwater flow directions and pollutant concentration gradients indicated that a contaminated groundwater plume has moved across the company track onto adjacent property along the southern and southeastern boundaries. There is currently no documented evidence of loss of liner integrity in the SIs, but state personnel have indicated that leakage from the ponds could be a source of pollution.

FACILITY D

REASON FOR REJECTION AS A CASE STUDY

The site is also in the immediate vicinity of Case Study No. 1, is owned by the same parent company, and has generally the same design and operating history and hydrogeological characteristics. Inclusion of this facility as a full case study was considered to bias the sample of facilities studied in this program. Operating practices are being modified at the site so that hazardous wastes will not be placed in the SIs after 1983.

GENERAL DESCRIPTION

Two on-site FML-lined ponds separated by a three-foot berm serve this metal products plant located in a semi-arid to desert area of the Southwest. The SIs were constructed in July 1980 and accept spent metal-containing highly acidic pickling solutions. The facility, located only two blocks from the facility in Case Study No. 1 and owned by the same parent company, has nearly identical hydrogeological and locational setting characteristics (see Case Study No. 1 for details). It is located in a heavily industrialized area with several major hazardous waste generators in the vicinity of the plant site. Soil conditions at the site include sandy upper soil with underlying colligie clay with the soil surface about 80 feet above the groundwater table.

SI DESIGN AND OPERATION (see Figure 30)

The SIs were designed and constructed by plant personnel. Foundation preparation included excavation followed by placement of 12 inches of clay and 12 inches of sand. The Palco chlorinated polyethylene liner was installed by a local contractor. The liner was laid out in three pieces which were glued together into place. A leak detection system designed to meet guidelines provided by state regulatory personnel was installed at each end of the SIs. Waste enters the SIs by means of pipelines. There are no outlets since they are primarily evaporation ponds.

SI PERFORMANCE

To date, there has been no evidence of leakage of the SIs based upon quarterly monitoring of the leak detection system located at both ends of the SIs. There are no groundwater monitoring wells at the site. There has been no visual evidence of deterioration of the liners to date.

FACILITY E

REASON FOR REJECTION AS A CASE STUDY

The owner/operator declined to participate in the study. There was not sufficient data available from other sources to allow a thorough analysis of this site.

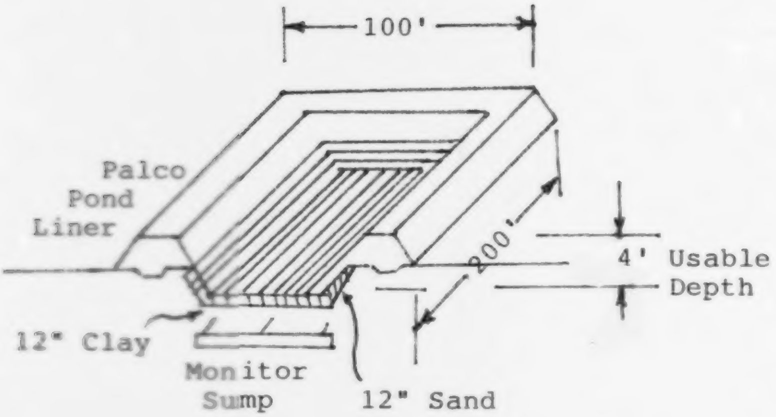

100'
Palco
Pond
Liner
200'
4' Usable
Depth
12" Clay
Monitor
Sump
12" Sand

Figure 30. Schematics of SI

(Figure depicts view of one SI; second SI is separated from first SI by a 3-foot beam)

GENERAL DESCRIPTION

This facility is a copper refinery producing copper products and certain metals as by-products from 99 percent pure blister copper and copper anodes. The site is in a predominantly agricultural area of the southwest with a dry steppe climate. Numerous domestic, agricultural, and industrial wells are in the general area.

Potentially hazardous wastes generated at this facility include industrial process wastewater, organic solvents, and various organic laboratory reagents. Chemical analysis of the process wastewater indicates a low pH, high TDS, and arsenic and selenium levels above EPA toxic limits. This wastewater, generated at the rate of 60 million gallons per year, is discharged to a lined holding pond prior to disposal in an injection well.

SURFACE IMPOUNDMENT DESIGN AND OPERATION

When the refinery went into operation in 1975, the company had planned to use several unlined waste disposal solar evaporation ponds. However, due to the occurrence of high permeability soils around the ponds and the presence of metals in the wastewater, the state required the use of a lined pond and injection well system.

One large pond with a capacity of over 13 million gallons was lined with a 30-mil Hypalon liner and used as a 90-day capacity holding pond prior to disposal by injection well. In late 1981, when this pond was drained for sludge removal, a second, smaller Hypalon-lined pond was constructed without prior state approval. At this time, the company claimed that the process wastewater was technically non-hazardous due to the exclusion from RCRA regulations of wastes from the refining of copper ore. The state, nevertheless, was concerned about the presence of metals, the low pH and high TDS in the wastewater and so required a leak detection and collection system be installed under the new pond. No ground water monitoring system was required or installed.

SURFACE IMPOUNDMENT PERFORMANCE

The liner of the large pond was damaged during the sludge removal operations and was subsequently repaired. In late 1982 holes were found in the liner of the new smaller pond above the normal water line. These holes were reportedly due to hail storms during June and July and went undetected for two months. The small pond was drained into the large pond to allow repair of that liner. At that time the site owner and the state had not agreed upon a suitable leak detection system.

FACILITY F

REASON FOR REJECTION AS A CASE STUDY

The owner/operator declined to participate in the study. There was not adequate data available from other sources to allow a thorough analysis of this site.

GENERAL DESCRIPTION

This facility is a manufacturing plant producing office supplies and equipment, printed circuit boards and metalized ceramic substrates. It is located near a city in a semi-arid area of the southwest. Various hazardous wastes are generated on-site. Most of the wastes are stored in tanks and drums. Two surface impoundments store process sludge containing metals. There are 3 or 4 supply wells on-site.

SURFACE IMPOUNDMENT DESIGN AND OPERATION

There are two large double-lined ponds on-site. They each have a capacity of one million gallons. They receive electroplating sludge from the manufacture of printed circuit boards. The waste is a 20 percent solids mixture generated at the rate of over 160,000 gallons per year. Metals present in the sludge include nickel, chromium, copper, magnesium, iron, and tin.

SURFACE IMPOUNDMENT PERFORMANCE

No information was available regarding surface impoundment performance. A ground water monitoring system was required in late 1981. Monitoring wells were installed; contaminant indicators measured are pH, conductivity, total organic carbon, and total organic halogens.

FACILITY G

REASON FOR REJECTION AS A CASE STUDY

The owner/operator declined to participate in the study. There was not enough data available from other sources to allow a thorough analysis of this site.

GENERAL DESCRIPTION

This facility is a 1,225-acre oil refinery and petrochemical complex. Oil refinery production is 65,000 barrels/day. Both hazardous and non-hazardous wastes are generated. Facility operations began in 1929; however, most of the hazardous waste disposal systems were constructed in the 1970s. The site is near a small southwest city with a dry steppe climate. The surrounding area is industrial and agricultural with some residences. The underlying soils are of high permeability loam, sand, gravel and clay. The ground water table is 30 to 100 feet below the surface. Numerous domestic and agricultural wells are in this general area.

SURFACE IMPOUNDMENT DESIGN AND OPERATION

The surface impoundments on-site were designed to receive wastewater from an API separator and plant runoff. The wastewater is discharged to a 7,000 gallon pond used for settling and oil removal. From this pond, overflow is directed to a large 90 million gallon dammed reservoir. This reservoir is called Refinery Lake and was designed for containment and evaporation of the API separator wastewater and plant runoff. Both ponds are lined with a 14% asphalt, 86% soil admixture of undetermined thickness and a permeability of approximately 2 x 10^{-6} cm/sec.

SURFACE IMPOUNDMENT PERFORMANCE

Prior to 1975, wastewater was discharged to unlined holding ponds. Heavy rainfall caused the surface impoundments to overflow, allowing wastewater and runoff to flow overland to a nearby creek which empties into a large river. Seepage from the unlined ponds caused ground water contamination as evidenced by high phenols and TDS content with some heavy metals. The lined ponds were then constructed and a ground water study was initiated. Concern was voiced by the state that the phenols in the waste would not be compatible with an asphaltic liner. However, the asphalt-lined ponds are now in use. No information was available regarding liner-waste compatibility. In late 1981, the process wastewater was diverted away from Refinery Lake into a "water flood feed system" and so the lake now receives only plant runoff. A ground water monitoring program was begun in early 1982.

FACILITY H

REASON FOR REJECTION AS A CASE STUDY

The liner of the storage pond is underlain by reinforced concrete; the system is not technically a surface impoundment but rather a tank.

GENERAL DESCRIPTION

This facility is a manufacturing plant producing industrial petrochemicals and synthetic rubber. It is situated on the banks of a river near a small city in a semi-arid area of the southwest. Several hazardous wastes are generated and treated on-site. The wastewater from these treatment facilities is retained in a polishing basin for several days prior to discharge to the river. A wastewater discharge permit has been issued which regulates the cyanide and mercury contents of the discharged wastewater. There is also a storage lagoon for caustic wastes on-site.

SURFACE IMPOUNDMENT DESIGN AND OPERATION

The storage lagoon is lined with reinforced concrete and so is technically not a surface impoundment but rather a storage tank. The polishing basin receives treated wastewater and since it is allowed to discharge into a river, it may be assumed that its content is not hazardous.

SURFACE IMPOUNDMENT PERFORMANCE

No discussion of surface impoundment performance is presented because this facility technically does not have surface impoundments in use.

FACILITY I

REASON FOR REJECTION AS A CASE STUDY

This site was found unsuitable for performance analysis due to the presence of other on-site land disposal technologies. Besides the surface impoundments which are currently active, the site also contains secure landfill cells and previously used but now abandoned impoundments, landfills, and land treatment areas. With the ground water monitoring system consisting only of perimeter wells, it is not possible to attribute any observed incident of contamination to a single specific source.

GENERAL DESCRIPTION

Facility I is a fully integrated commercial hazardous waste management facility. Treatment and disposal technologies available on site include high temperature incineration, chemical/biological/physical treatment, and land disposal. The site is located in a heavy industrialized area of the Southeast. It is on nearly level ground and is part of a terrace rising about 40 feet above the flood plain of a nearby large river. Normal annual precipitation is 54 inches which is about 12 inches in excess of the 42 inch evaporation rate for the area.

The surficial deposits beneath the site are predominantly silt and clay to depths of about 100 feet. The uppermost 20 to 25 feet consist of compact clay or slightly silty clay ($\leq 10^{-8}$ cm/sec). Underlying materials are also clayey, but contains thin lenses of sandy silts ($\leq 10^{-6}$ cm/sec.) Water in the sands are probably in isolated zones, under artesian or perched conditions. An aquifer of permeable deposits ($\leq 10^{-3}$ cm/sec) is located at a depth of 75 feet beneath the plant. Deltaic and flaviatile deposits contain freshwater sands separated by clays and shales to a depth of 2800 feet. Ten discrete aquifers have been identified in the area. Two fault systems have been mapped within four miles of the plant. One fault appears to be a major barrier to the movement of ground water.

Currently, the old landfill cells, covering an area of about 50 acres, are being excavated and the excavated material placed in the new secure cells. The plant closed its approximately 60-acre landfarm operation as a part of a settlement agreement with a state regulatory agency in 1981. Sludge from the landfarm was solidified and placed in the secure landfill. At least 5 acres of surface impoundments located throughout the plant site have also been closed. The contents of the ponds were incinerated and contaminated soil was placed in the secure landfill.

WASTES HANDLED

The facility handles waste of diverse composition and volume in liquid, semi-solid, and solid forms. The wastes are generated by major industries, such as chemical, petro-chemical, refining, synthetic polymer, etc. Incineration is used for combustible light liquids (aliphatic and aromatic hydrocarbons, alcohols), viscous liquids (aliphatic and aromatic oils, polyglycols, emulsions), and chlorinated hydrocarbons. Oil-water separator bottom sludge, waxes, tars, and rubber are also incinerated. Corrosive/caustic wastes and oil-water emulsions are chemically treated in ponds. Biological treatment is appropriate and used for selected organics.

Only stabilized solids are placed in the secure landfill cells. Acceptable wastes include trickling filter media, contaminated soil, tank bottoms and sludges, laboratory wastes, paint solids, waste gypsum, crushed drums, and incinerator ash. Sludges are pretreated with fly ash or incinerator ash.

Annual receipts of hazardous wastes associated with each method of treatment or disposal are as follows:

Treatment/Disposal Method	Amount (Tons/Year)
Landfill	350,000
Incineration	33,000
Chemical/Biological/Physical	1,300,000

SI DESIGN AND OPERATION

Liquid fractions of neutralized acid wastes are directed to an equilization treatment pond. Influent to the biotreatment facility is derived from the following sources: process wastewaters, contaminated runoff, and landfill leachate. Process wastewater may include tank trailer customer receipts and truck-wash rinse water. (These wastes are received in small individual ponds.) All waste water for biotreatment is directed to the equilization pond. Contaminated runoff is held in rainwater basins and released, as appropriate, to the equilization pond. Treatment in the equilization pond includes preliminary aeration, and pH, nutrient and organic loading adjustments. Biotreatment sludges are solidified and landfilled, while the liquid fraction is sent to a stabilization pond to settle out all remaining solids. Effluent from the incinerator-scrubber wastewater holding pond also goes into the stabilization pond. Total effluent from the stabilization basin is routed to an outfall for ultimate discharge to a nearby river.

All impoundments have 2:1 embankment slopes and are lined with 4 to 5 feet of clay compacted in 6 to 8 inch lifts. The ponds were designed by the owner and a geotechnical consultant. A construction contractor installed the liners and a second geotechnical consultant observed and monitored the installation. Liner permeabilities are less than or equal to 10^{-7} cm/second.

SI PERFORMANCE

A ground water monitoring system consisting of 21 perimeter wells was installed at the facility in late 1980. Ten wells are designed to monitor water quality in the uppermost permeable strata at depths of 24 to 49 feet. Seven separate wells monitor a second permeable stratum between 50 and 80 feet. In addition, four deep wells, between 115 and 129 feet, have been installed. The wells are located in a manner such that contaminated flow would be detected promptly (See Figure 31). However, as to the source of contamination, it is not possible to attribute contamination to a single specific unit based on water quality data from these wells.

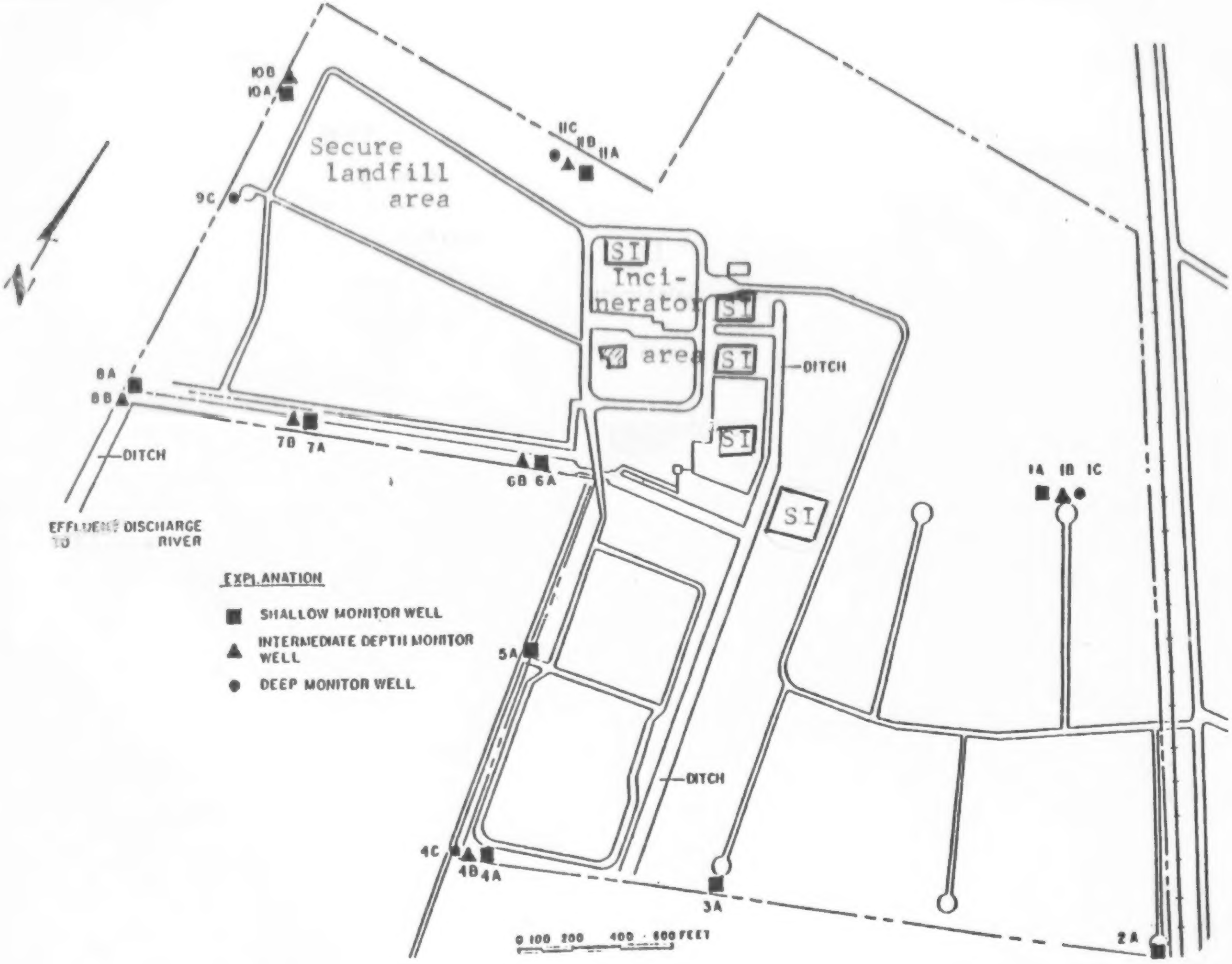
Figures 31 and 32 show the approximate location of present and past disposal technologies, respectively. As seen in these figures, the technologies are all located very close to each other and even at the same place at different times. Only three years ago the old landfill could be described as an open dump containing free liquids. At least 12 of the old impoundments (closed in 1981 and 1982) were unlined. Since none of the ponds have leak detection systems under the liners, it is not possible to assess the performance of any individual pond. (Only the new landfill cells have such leak detectors.)

Although the correspondence in the State files include references to past ground water contamination, actual data on ground water monitoring results could not be located in the files. Such data are apparently retained in the Company files.

FACILITY J

REASON FOR REJECTION AS A CASE STUDY

The owner/operator declined to participate in the study and there were not enough data available from other sources to provide a basis for design-performance evaluation.


10B
10A
11C
11B
11A
Secure landfill area
9C
SI
Inci-nerator
SI
area
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SI
DITCH
8A
8B
7B
7A
6B
6A
DITCH
1A
1B
1C
SI
EFFLUENT DISCHARGE TO RIVER
EXPLANATION
■ SHALLOW MONITOR WELL
▲ INTERMEDIATE DEPTH MONITOR WELL
● DEEP MONITOR WELL
5A
DITCH
4C
4B
4A
3A
0 100 200 400 600 FEET
2A

Figure 31. Layout of Existing Technologies and Monitoring System

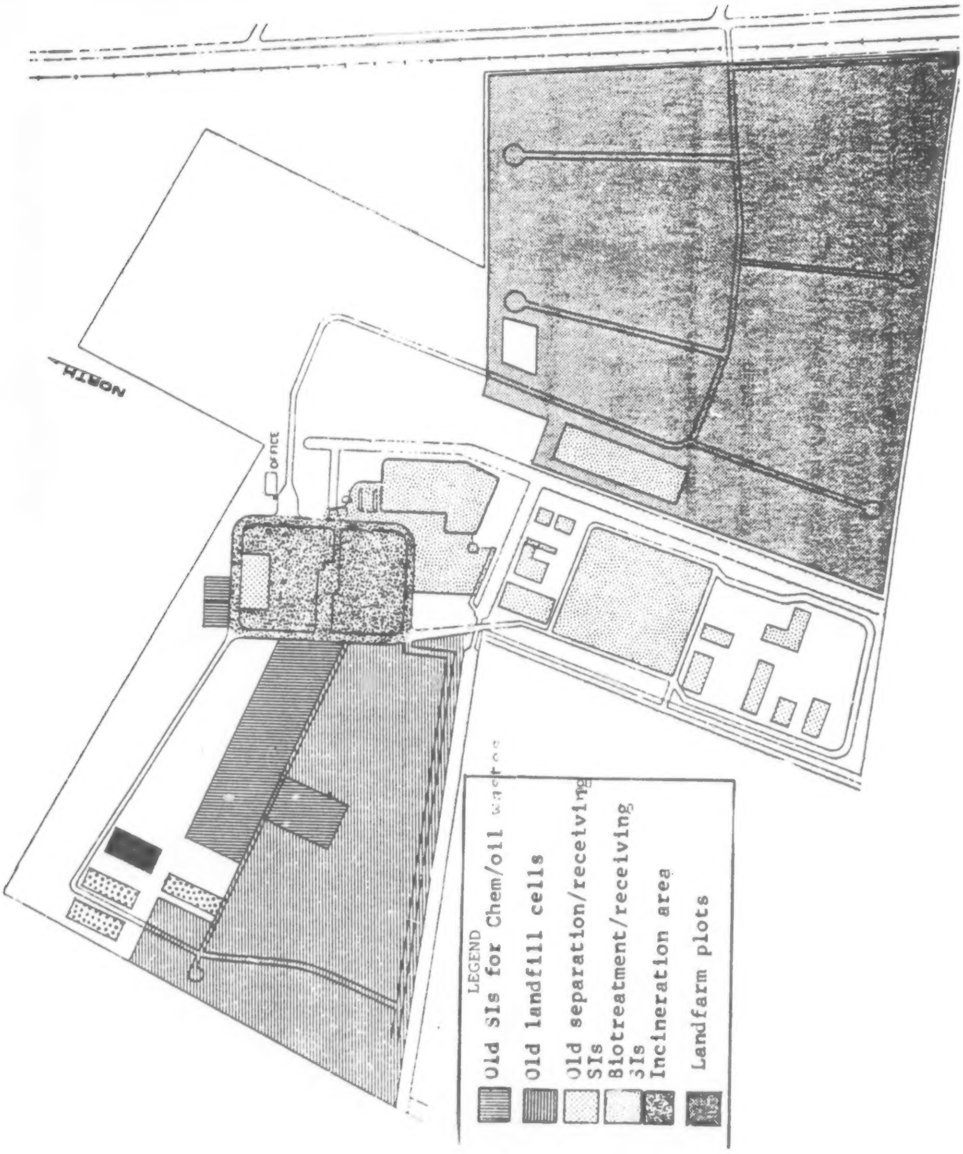
NORTH
office
LEGEND
Old SIs for Chem/oil wastes
Old landfill cells
Old separation/receiving SIs
Biotreatment/receiving SIs
Incineration area
Landfarm plots

Figure 32. Location of Past Treatment/Disposal Practices

GENERAL DESCRIPTION

This chemical manufacturing facility is located on a 3,500-acre plot about 4,000 feet from the banks of a large river in the Southeast. About 900 acres of the area are presently occupied by operating chemical plant facilities that produce butadiene, ethylene, propylene, diammonium phosphate, hydroflouric acid, aluminum fluoride, debutanized aromatic concentrate, urea, anhydrous ammonia, nitric acid, ammonium nitrate, phosphoric acid, and sulfuric acid.

The site is relatively flat. The area is underlain by alluvial deposits of recent origin. A 40 to 80 foot thick soft to medium strength clay layer, with thin pockets and layers of sand and silt material, overlies firm, dense to very dense, fine sand and silt. The clay is highly impermeable but structurally weak; the sands and silts are pervious and comparatively much stronger. The strong sand and silt stratum continues to depths of several hundred feet. The depth to bedrock is several thousand feet. Depth to ground water at the plant site is 6 to 15 feet. The depth to ground water can fluctuate with rainfall, seasonal variation, and river stage.

During normal operation of the plant, certain wastes are generated which necessitate treatment, disposal, or discharge to the river under permit. State permits have been issued for the following items:

- Nitrogen area "Belco" pond.
- On-site disposal in gypsum stacks of by-product gypsum and other wastes resulting from the production of phosphoric acid and phosphate fertilizers. This includes 120 acres of existing gypsum pond area for stacking.*
- On-site disposal in gypsum stacks of by-product gypsum and other wastes resulting from the production of hydrofluoric acid and aluminum fluoride and from the lime treatment unit. This includes 30 acres of existing ponds for stacking.*
- A drum storage facility for hazardous waste stored in drums for longer than 90 days.
- Discharge of wastewater through three outfalls to a river.

Estimated quantities of wastes handled are presented in Table 40.

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*These wastes generated as a direct result of mining and ore processing (phosphate rock) operations, fall under the mining waste exemption of 40 CFR 261.4(b)(6), and hence, are not hazardous wastes regulated by RCRA.

TABLE 40. ESTIMATED QUANTITIES OF WASTES HANDLED AT FACILITY J

FACILITY	WASTE TYPE	ESTIMATED QUANTITY (T/Yr)
Belco pond	Treated wastewaters	250,000
Gypsum ponds	Phosphoric acid by-product gypsum	735,000 (dry)
HF Gypsum ponds	Hydrofluoric acid by-product gypsum	340,000 (dry)
	Aluminum fluoride and aluminum hydrate	800 (dry)
	Lime treatment underflow	8,100 (dry)
	Lime waste (grit)	170 (dry)
Storage facility	Oils, solvents, sludges, misc. organics	0 - 50

SI DESIGN AND OPERATION

The nitrogen area Belco pond is designed to collect wastewaters generated in the water treatment unit, and condensate stripper and vessel cleaning solution. The amount of water collected will vary from day to day and year to year depending mostly on rainfall. (Rainfall runoff from the gypsum stacks is treated with lime and then discharged to the Belco pond.) The wastewater from the Belco pond is gravity fed to a neutralization facility prior to being discharged to the river.

Large volumes of by-product gypsum and other wastes resulting from the production of hydrofluoric acid and aluminum fluorides and from lime treatment are generated at the complex and are disposed of on-site in the HF-gypsum ponds. The exisitng HF-gypsum stack covers 20 acres, and an additional 10-acre stacking area (pond) was recently constructed. By-product gypsum from the phosphate production area is disposed of on-site in 120-acre phosphate-gypsum pond. Based on production rates, an additional 60 acres will be needed about every ten years and an additional 10 acres will be needed every four years for the phosphate-gypsum and HF-gypsum ponds, respectively.

The gypsum ponds and the Belco pond all have natural in-place clay or installed clay liners. A 40- to 60-foot thick soft to medium strength clay layer, containing thin pockets and layers of granular (sand and silt) material, underlies the phosphate-gypsum ponds. These ponds consist of four nominal 30-acre gypsum pond stacking-sections and an auxiliary clearwell area. A system of exterior dikes, to provide initial containment of gypsum slurry (starter dikes) and channelization of stack toe seepage (interceptor ditch dikes), define the impoundment sections and auxiliary clearwell. There is also a tertiary dike for acid water containment in the event of catastrophic stack slope failure. Average permeability of the dikes and recompacted clay liner sections is 2 x 10^{-8} cm/sec.

The HF-gypsum ponds were designed and constructed in a manner similar to that of the phosphate gypsum ponds. Natural deposits beneath these ponds consist of medium to stiff silty clay and clay with some organics and silt seams. Clay, silty clay, and silt layers were encountered to the depths of up to 75 feet. Permeabilities of in situ clay ranged from 10^{-7} to 10^{-9} cm/sec using water and an acidic liquid (similar to the waste to be impounded) as the permeating fluids. For the 10-acre expansion of the HF-gypsum ponds, the owner/operator required a minimum clay thickness of 5 feet.

Stability analysis of the stacks were conducted prior to expansion of both phosphate and HF-gypsum ponds. The owner used two different geotechnical consultants to design the HF and phosphate pond expansions. In regard to dike construction, one consultant recommended that moisture content be kept between 2 and 6 percent wet of optimum and compaction be to at least 90 percent of maximum clay density; the other consultant recommended that sufficient compaction be exerted on loose lifts so that air voids are removed and a permeability $<10^{-7}$ cm/sec is obtained.

SI PERFORMANCE

Because the owner declined to participate in this study and there were not enough data available from other sources, a meaningful performance analysis cannot be provided. However, some performance data provided by the state are discussed here.

Due to the low vertical permeabilities of the confining clay layers beneath the ponds, the potential for leakage to reach the fresh ground water zone beneath the plant is considered to be smaller than the potential for horizontal flow to reach surface waters in shallow silt/sand layers. In order to verify the potential for horizontal movement of wastewater from the HF stack, soil samples were collected and analyzed for selected trace metals in 1980. The results were considered inconclusive because the data did not seem to offer a very clear pattern of contamination.

The ground water monitoring system at this site consists of 9 perimeter wells around the phosphate-gypsum ponds, 6 perimeter wells surrounding the HF-ponds, and 2 wells at the Belco pond (See Figure 33). Ground water monitoring statistical analysis data were available for the second quarter of 1983. These data were compared by the state to the first year's background data obtained from the same wells in 1981.

The statistical analysis indicated a total of 16 significant changes in 10 different wells. However, seven of these are apparent changes to a lower concentration and were disregarded. Subsequent resampling of those wells indicating a significant increase in contamination showed that only the

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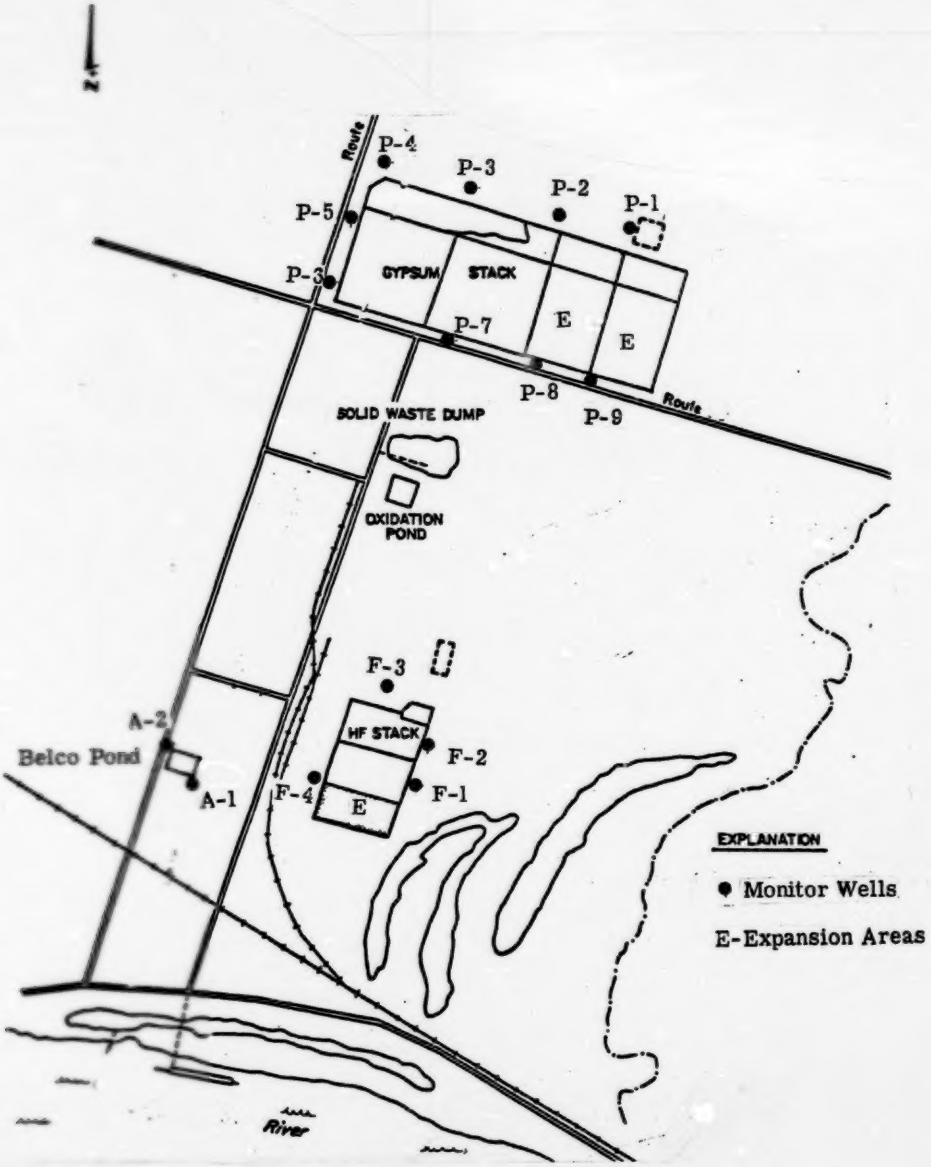
N
Route
P-4
P-3
P-2
P-1
P-5
P-6
GYPSUM STACK
E
E
P-7
P-8
P-9
Route
SOLID WASTE DUMP
OXIDATION POND
F-3
HF STACK
F-2
F-1
F-4
E
A-2
Belco Pond
A-1
River
EXPLANATION
● Monitor Wells
E-Expansion Areas

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Figure 33. Facility J Pond and Monitoring Locations

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EPA-287 (Cin.)
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sulfate analysis for well P-8 stayed above the upper 95 percent confidence limit.

Assessment of the problem (by the state) indicated that the change in sulfate in well P-8 may have been due to inappropriate siting and screen depth of that well. The well is in such proximity to the phosphate-gypsum stack and is so shallow (screen from 4 to 9 feet below grade) that it may be monitoring the facility itself rather than migration from it. Also, the change may be due, in part, to surface contamination since the well screen is located so close to the ground surface and gypsum stack water management ditches. An example of the monitoring results is provided in Table 41.

TABLE 41. GROUNDWATER MONITORING QUARTERLY REPORT

(Second Quarter, 1983)

	Well Number			
	F-1	F-2	F-3	F-4
Date Sampled	4-11-83	4-11-83	4-11-83	4-11-83
Water Temperature, °C	19.5	19.3	20.0	19.5
Water Surface Elevation,MSL(Ft.)	17.2	17.1	16.6	18.7
Contamination Parameter (1)				
pH, S.U.	6.5	6.5	6.6	6.6
Spec. Cond, mho/cm	1900.	2000.	1000.	519.
Fluoride, mg/l	1.77*	1.62	.98	.65
Sulfate, mg/l	1830.	1282.	322.	37.
Aluminum, mg/l	<.02	.16	<.02	.09
TOC, mg/l	3.7	2.2	1.8	1.7

NOTES:

*Exceeds primary drinking water standard.

(1) Concentrations are the arithmetic average of quadruplicate analysis.

(2) Except for pH, conductivity, and TOC, the well samples were vacuum filtered through a Whatman #42 filter paper prior to sample splitting, preservation and analysis performed.

FACILITY K

REASON FOR REJECTION AS A CASE STUDY

The owner/operator declined to participate in the study indicating that the monitoring data which are now being generated are as yet insufficient to allow meaningful assessment of the pond's performance. When sufficient data become available (perhaps in about a year), such data would have to receive extensive internal review before they can be released for outside use. The onwer/operator also declined to provide data on the design of surface impoundments at this facility.

GENERAL INFORMATION AND HISTORICAL BACKGROUND

This chemical manufacturing plant is located on the Pacific Coast next to a large river. The operator manufactures chlorine, sodium hydroxide, hydrogen, latex, agricultural chemicals, fumigants, fungicides, and chlorinated solvents. The operator also packages anti-freeze, conducts chemical development research, and treats raw and waste waters. Solid waste materials have been disposed of in various locations within the current boundaries of the plant since 1916. The plant property includes sections of land used as a former municipal garbage dump before the current owner acquired the land.

Solar evaporation ponds are utilized for on-site disposal of hazardous wastes. All hazardous wastes generated at this site are either disposed of via these solar evaporation ponds, if appropriate, submitted for off-site disposal, or rendered non-hazardous and made suitable for reuse by further processing and recycling.

Waste disposed to solar evaporation ponds has been historically, and is currently comprised of dilute aqueous waste and potentially contaminated water generated from production processes associated with the manufacture of commercial chemicals. Typical waste materials include: 1) spent scrubber solutions consisting of 2 to 4% excess sodium hydroxide, 4 to 8% sodium chloride, 1 to 5% sodium hypochlorite, and <1% chlorinated picolines and other chlorinated hydrocarbons; 2) loading sump rinsings typically consisting of rain and fire water, process slab washings with about 1% sodium chloride, sodium sulfate, and sodium hydroxide, small amounts of sulfones, iron oxide, 1% ethylene glycol, and polyethylene glycol; and 3) research laboratory sink washings consisting of small amounts of alcohols, ketones, and dissolved organic and inorganic salts. The discharge rate is >50,000 gallons/day.

SURFACE IMPOUNDMENT DESIGN

Six solar evaporation ponds (Ponds A-F) currently serve this facility. Various FMLs have been used in the construction of these ponds. A 10-mil polyethylene and a 45-mil CPE liner were used to line some of the ponds in 1968 and 1979, respectively. The construction sequence for Ponds B, C, D and F was apparently as follows: (a) the subgrade was compacted to 90% of standard Proctor density, (b) fill material was placed and compacted to form embankments which typically have 20-ft crest and 2:1 (H:V) slopes, and (c) the FML was placed over the subgrade followed by a smooth gravel underdrain layer with 4-in collector pipes, a thin layer of compacted soil cement and 2 ft of compacted clay. Compacted clay was also used to line the internal embankment slopes. The average clay permeability is approximately 10^{-8} cm/sec.

The construction of Ponds A and E apparently differs from that described above for Ponds B, C, D and F. These ponds are double lined, with 45-mil Hypalon replacing the compacted clay as the primary liner.

SURFACE IMPOUNDMENT PERFORMANCE

As noted above, the owner/operator is currently monitoring site performance, but believes that the data accumulated to date are insufficient to permit meaningful performance assessment. The state is currently in the process of issuing a permit for the impoundments. The permit would require ground water monitoring and use of leak detection system and reporting of the results to the state.

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APPENDIX B

MISCELLANEOUS SUPPORT DATA

LINER INSTALLATION SPECIFICATIONS FOR EVAPORATION AND COOLING PONDS IN CASE STUDY NO. 4. (The name of the company involved has been omitted.)

1.0 GENERAL

The work covered by these specifications consists of furnishing all labor, supervision, equipment, and material necessary to install approximately 1,584,800 ft.^{2} of polyvinyl chloride (PVC-12 mil) plastic liner on the bottom of the evaporative and cooling ponds, 302,652 ft.^{2} of reinforced material made of ethylene propylene diene monomer (E.P.D.M.)-30 mil - on the evaporative and cooling pond slopes, 35,600 ft.^{2} of polyethylene (4 mil) in monitoring drain system as shown on the drawings and directed by a — engineer. All liner areas are approximate values and should be verified in the field by the contractor prior to bidding. Use of water soluble compounding ingredients is prohibited. Plasticizers that are predominantly resistant to migration, mildew, and bacterial degradation shall be used. The sheeting shall be pigmented to produce a uniform color. All structures, headwalls, inlets and outlets shall be set and finished (by others) prior to liner installation. All work shall be done in strict accordance with the drawings and specifications of both — and the manufacturer. If a conflict occurs, the — engineer will decide which takes precedence. All work shall also be subject to the terms and conditions of the contract.

2.0 PREPARATION OF SURFACE (BY OTHERS)

The surface on which the liner is to be laid shall be generally smooth and free from loose earth, rubble, sharp objects and other foreign matter. Prior to installation of the liner, contractor shall inspect the surface and advise — engineer in writing that the surface preparation is adequate and ready for liner. Any sterilant used on soil will be tested for reactions with liners by — and liner contractor will be notified in writing on the test results.

3.0 PLACING LINER

All liners shall be protected from wind billowing during installation by scattering fill material (available at site) over the liner as necessary.

EPA-287 (Cin.)
(4-76)

The liners shall be placed over the prepared surfaces to be lined in such a manner as to assure minimum handling. The slope liner will be installed first to insure easy access to vertical field seams. Any portion of lining damaged during installation shall be removed or reparied by using an additional piece of similar liner material as specified hereinafter.

4.0 MATERIAL TESTING

All tests on liner material will be conducted by an independent testing laboratory under the direction of — (all fees for tests will be paid by —. Contractor will furnish, at his expense, all necessary liner material for standard laboratory tests designated by —. Liner material will be tested prior to delivery and marked so that can be assured that liner tests are on the actual liner installed. Liner shall be subject to spot testing when installed at the descretion of — Engineer. — will furnish contractor with the concentrations of the pond constituents and contractor will furnish confirmation, in writing, from the manufacturer that the specified liners will not deteriorate when exposed to these pond constituents. (See Monitoring System, Section 13.0.)

5.0 EARTH COVER ON LINER

During placing of earth cover over lining, care shall be taken to ensure that the membrane is not struck, gouged or otherwise damaged by equipment operating over the liner or by objects in the backfill. Earth material for covering the plastic lining shall be free of sharp rocks, rocks larger than 2 inches, wire or any other material which could damge the plastic lining. Earth cover shall be placed with conveyor equipment which will prevent equipment from operating on the lining material when fill is being placed. The method of placing the earth cover and the equipment to be used shall be approved by — Engineer prior to doing the work. The earth cover shall not be rolled or otherwise compacted, but shall be left in a loose, uncompacted condition.

6.0 POLYVINYL CHLORIDE LINER

6.1 General

The film shall be 12-mil thickness ±10% and shall be manufactured from 100 percent domestic virgin resin specifically compounded for use in hydraulic facilities. Individual widths of PVC plastic lining material shall be factory fabricated into (36 feet minimum width) sections by electronic bonding. A minimum joint width of 1/2 inch for electronic bonded joints is required. After fabrication, the sections shall be accordion-folded in both directions and packaged for minimum handling in the field. Liner shall be packed so as to prevent damage to sheeting during shipment. Packages will be inspected by — Engineer before opening in the field. Packages showing evidence of penetration or other damage will be rejected or repaired at the site.

TYPING GUIDE SHEET

6.2 Material Physical Characteristics

The 12 mil PVC liner material shall have the following physical characteristics:

PVC SPECIFICATION

Test	Specification Limits	Test Method
Color	Grey	
Thickness	12 mil ±10% (evap.-cool. pond bottom) 30 mil ±10% (drain sys. and set. ponds)	ASTM D374-C
Specific Gravity	1.24 to 1.30	ASTM D792-B
Tensile Strength-Long. and Trans.	2200 psi (min)	ASTM D882-A
Elongation-Long. and Trans.	250% (min)	ASTM D882-A
Modulus - 100% strain Long. and Trans.	1000 psi (min)	ASTM D882-A
Graves Tear-Long. and Trans.	270#/in thickness (min)	ASTM D1004
Acid Resistance -		
1. 0.001N sulfuric acid pH-3 (max)		ASTM D1239-55-71
2. 0.001N phosphoric acid pH-3 (max)		
Volatility	1.5% (max)	ASTM D1203-67
Bonded Seam Strength - Percent of Tensile	80% of original tensile strength (min)	ASTM D882-A
Resistance to burial conditions		
1. Tensile strength change	±5% (max)	ASTM D3083-72T
2. Elongation loss	20% orig. elong. (max)	
Alkali Resistance		
1. Change in weight after 7 days	-0.1% +0.25% (max)	Passes Corps of Eng. CRD-572-74
2. Change in shore durometer after 7 days - hardness		
Coefficient of permeability-K water vapor	10^{-8} CM/SEC or 8.64 Grams/M^2 24 hrs. (max)	ASTM E96-72 (procedure B.W.)
Pinholes and Cracks	1/10 yd^2 (max)	ASTM D3083-72T

NOTE: Tests will be conducted by independent laboratory at — discretion.

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7.0 REINFORCED LINER - POND SLOPES

7.1 Lamination Specs

The liner shall consist of two 15 mil sheets laminated together with polyester scrim 10 x 10 (1000 denier) between the two calendered sheets. The scrim shall be dipped in cross linking adhesive and oven or air blown dry prior to lamination. The reinforced liner shall be 30 mil thickness ±10% and shall be manufactured from 100 percent domestic virgin resin specifically compounded for hydraulic facilities. The final product, after attachment to PVC, shall have encapsulated edges and shall not be subject to delamination under normal fabrication, installation, or service conditions in the field.

7.2 Factory Sections

Individual widths of reinforced lining material shall be factory fabricated into sections by a vulcanized seam using a minimum joint overlap of 4 inches (scrim to scrim).

7.3 Slope Seams

Finished slope panels shall be fabricated in such a manner that all factory joints shall be oriented in a vertical direction down the slopes. No horizontal field seams will be allowed on the slope areas.

7.4 Slope and Bottom Material Attachment

E.P.D.M. slope material shall be attched to P.V.C. bottom material with a min 6 inch horizontal overlap seam. E.P.D.M. will be placed on top of the P.V.C. to make the horizontal seam. All 6 inch seams between E.P.D.M. and P.V.C. shall rest in a horizontal plane and at no time will this seam be installed on the slope.

7.5 Material Physical Characteristics

The reinforced E.P.D.M. lining material shall have the following characteristics:

REINFORCED E.P.D.M. SPECIFICATION

Test	Specification Limit	Test Method
Color	Black, Standard	
Thickness	30 mil ±10% (Evap.-Cooling pond slopes)	ASTM D374-C
Specific Gravity	1.15 to 1.20	ASTM D792-B

REINFORCED E.P.D.M. SPECIFICATION (Continued)

Test	Specification Limit	Test Method
Acid Resistance		
1. 0.001N sulfuric acid (pH-3)	0.30% max. wt. loss	ASTM D1239-55-71
2. 0.001N phosphoric acid (pH-3)	0.30% max. wt. loss	
Volatility	1% max. wt. loss	ASTM D1203-67
Tensile Strength	Long 3500 psi (min) Trans 3000 psi (min)	ASTM D751-68 (2 in. strip min)
Modulus - 100% strain	Long 1000 psi (min) Trans 1000 psi (min)	ASTM D751-68 (2 in. strip min)
Bonded Seam Strength Percent of Tensile	100% of original tensile strength (min)	ASTM D-412-72
Elongation (supported materials)	Long 300% (min) Trans 300% (min)	ASTM D751-68 (2 in. strip min)
Dimensional Stability	212°F - 10% (max) 158°F - 3% (max)	ASTM D1204-54-71
Coefficient of permeability-K water vapor	10^{-8} CM/SEC or 8.64 Grams/M^2 24 hrs (max)	ASTM E96-72 (procedure B.W.)
Alkali Resistance		
1. Change in weight after 7 days	-1% to +0.25% (max)	Passes Corps of Eng. CRD-572-74
2. Change in shore durometer after 7 days - hardness	±5% (max)	
Resistance to burial conditions		
1. Tensile strength change	±5% (max)	ASTM D3083-72T
2. Elongation loss	20% (orig. elon.)	
Pinholes and Cracks	0	ASTM D3083-72T

NOTE: Tests will be conducted by independent laboratory at — discretion.

8.0 LINER SEAMS

8.1 Field Seams

Seaming of liner to itself in the field shall be accomplished as recommended by the liner manufacturer. Overlap seams will be used to seal factory fabricated sections together in the field. Overlap seams shall be formed by lapping the edges of panels a minimum of 4 inches. The contact surfaces of the panels shall be wiped clean to remove all dirt, dust or other foreign materials. Sufficient cold-applied bonding adhesive shall be applied to the contact surfaces in the joint area, and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out. All free edges of E.P.D.M. liner seams shall be resealed with manufacturers recommended lap sealant or tape to attain a watertight joint.

8.2 Testing Seams

All field seams will be properly tested and verified by a representative. Factory bonded seams will be randomly tested as designated by a — Engineer. All field and factory seams, patches and any other areas, as determined by a — Engineer, shall be vacuum leak tested by and at the expense of the contractor in the presence of a — Engineer.

8.3 Seam Testing Procedure

The vacuum box for vacuum testing shall be of sufficient strength to withstand a vacuum of 10 inches H_2O. The top of the box shall have a window of sufficient size and transparency to permit close observation of the area being tested. The box shall be of such size, shape and design to permit testing all areas requiring the test. It shall have proper valves and gauges necessary to permit the test. All areas tested shall be cleaned of all dust, debris, dirt and other foreign matter. A soap solution shall be applied to the test area with a paint roller, and the vacuum box immediately placed over the area of the lining to be tested for the inspector to record any leaks. Any leaks revealed by the vacuum test shall be reparied by and at the expense of the contractor at time of discovery. The American Vacuum Seam Tester or equal will meet all of the above specifications.

8.4 Seaming to Structures

The liner shall be closely fitted and sealed around inlets, outlets, and other projections through the liner. Liner attachments to all structures shall be accomplished by adhering strictly to detail drawings.

9.0 ANCHORING LINER TO DIKES

The top edge of the liner shall be anchored by a trench 12 inches deep and 8 inches wide. (See detail drawing.) Walls on both sides of the trench and the bottom of the trench shall be covered with the liner as shown on the detail drawings. The anchoring trench shall be dug in the pond dikes and located as per drawings. The trench shall be backfilled and properly compacted to 90 percent on the Proctor Scale per ASTM D698.

10.0 ADHESIVES

The contractor shall use adhesives that are recommended by the liner manufacture. The adhesive will prove durable when subjected to both sun and water exposure, and use of the adhesive shall not cause any appreciable stiffening of the liner. Six copies of manufacturer's specification on adhesives to be used for all the liners shall be furnished to — prior to job commencement.

11.0 INSPECTION

The — Engineer will inspect continuously. Any work not done in compliance with the specifications and the manufacturer's instructions shall be repaired or replaced as required for a satisfactory job by the contractor.

12.0 REPAIRS TO LINER

All necessary repairs to the liner shall be made using the liner section cut large enough to extend no less than 4 inches beyond the damaged areas in all directions and sealed all around with the proper adhesive. Method of application shall be as specified above for field seams. All repairs shall be tested in accordance with section on Seam Testing.

13.0 MONITORING SYSTEM

The monitoring system shall be placed in a "V" ditch, lined with 30 mil PVC, which will meet all specifications for PVC. The "V" ditch will be compacted after excavation to 95 percent on Standard Proctor Scale per ASTM D698. The 3 inch diameter drain pipe shall be able to exist, without deterioration, in a liquid with a pH of 2 with a maximum temperature of 110°F and composed of following maximum concentrations by weight:

1. 0.5% Sulfuric Acid
2. 1.63% Phosphoric Acid
3. 0.05% Chlorides
4. 0.5% Fluorides
5. 1% Organics

The pipe will be perforated with 1/4 inch diameter holes approximately 90 degrees apart on 2 feet centers. All joints will be coupled according to manufacturer's specification. Contractor will verify in writing, that the material and adhesive used for the drain pipe will withstand the above pond chemical compositions and burial pressures imposed by the soil, in accordance with detail drawings. One-half inch (1/2") to 1 inch (1") diameter well-rounded river rock will be used to cover the drain pipe as shown on drawings. A 4 mil polyethylene cover over the river rock will be installed per drawings. Fill material furnished by — and installed by the liner contractor will be firmly placed over the polyethylene liner to bring the pond bottom back to its original elevation. The dikes shall be brought back to their original compaction where the monitoring system has been installed. The drain pipe will slope at 0.25 percent and terminate in a 4 foot diameter reinforced concrete catch basin as shown.

14.0 SETTLING PONDS

The two settling ponds will be lined (bottom and slopes) with concrete. An approach ramp will be provided (by others) for each settling pond. (See drawings for concrete details.)

15.0 FILLING PONDS AFTER LINER IS INSTALLED

— will provide for filling ponds with approximately 2 feet of water immediately after completion of liner installation. All necessary pumps, additional piping and connections needed will be at — expense. Contractor will provide manpower to conduct a final test to see that all seams are watertight.

16.0 CLEANUP

Before contractor finishes work he shall remove all surplus materials from pond and surrounding areas. Upon completion contractor will go through a final clearance checkout with — Engineer.

17.0 WARRANTEES - GUARANTEES

17.1 Manufacturer's Warranty

All materials shall be guaranteed free of defects for a period of 10 years from the date of completion. The guarantee will be on a pro-rata replacement cost basis and shall cover normal wear and exposure for this application.

17.2 Installer's Guarantee

Workmanship of installation contractor shall be guaranteed for a period of one year from the date of completion. If it appears within one year from the date of completion that the installed liner, or any part thereof, does not conform to this guarantee and — so notifies installer within a reasonable time after discovery, installer shall thereupon promptly correct such nonconformity at his sole expense and shall extend the applicable guarantee for one year following this corrective action.

18.0 CONCRETE VENEER

A cover of wire-reinforced concrete veneer shall be placed over the inside levee of the settling basin slopes as shown on the drawings. A 1 x 1 inch 20-gauge poultry mesh wire shall be placed in a continuous layer, with adjacent edges overlapping 2 inches minimum and secured to one another by the use of "hog rings" or other appropriate clips. The concrete shall be placed over the wire with a nominal thickness of 2 inches. All wire shall be covered with concrete such that no wire is visible on the surface or edges of the concrete. The concrete shall consist of a minimum 5-sack mix, Type V Portland Cement and a maximum aggregate size of 3/8 inch. Concrete veneer will be poured from the bottom of the pond up the slopes in a continuous pour. The concrete shall have a broom-finish and be water cured to prevent excessive cracking. Expansion joints will be used to prevent the veneer from cracking.

19.0 GLOSSARY

Bottom Liner - Liner to be placed on all pond bottoms which will be in a horizontal position.

Slope Liner - Liner to be placed on all inside slopes (3 horizontal to 1 vertical) of pond dikes.

Overlap Joint - All liner joints which are either horizontal or sloped up the inside of dike, always support by underlying soil.

Scrim - The reinforcement that is laminated between the two sheets of liner. The scrim used will be 10 strands (both ways) per 1 inch of liner, with 1,000 denier dacron/polyester material.

Encapsulated - Completely encased. All scrim in E.P.D.M. liner shall be completely laminated after attachment to PVC so that it is never exposed, including the ends of each section.

By Others - This means that work will be done by contractor other than liner contractor.

Contractor - Pond liner contractor.

20.0 REFERENCE DRAWINGS

Drawings relating to the pond liner at the facility are Numbers 42542-2, 41576-4 and 41575-2.

CONSTRUCTION SPECIFICATIONS FOR POND 6, CASE STUDY NO. 5*

2.0 SITE PREPARATION AND EARTHWORK

2.1 General

The work to be performed under this section shall include the furnishing of all labor, materials, and equipment necessary for site preparation, excavation, hauling, placing, and compaction of required fill materials, backfill, and embankments to the lines and grades indicated on the plans and as specified herein.

Specific methods of materials handling, conditioning, placement and compaction in accordance with the plans and technical specifications shall be submitted by the Contractor for written approval by —. After a limited trial period has demonstrated their effectiveness, specific construction procedures will be approved by — but shall not relieve the Contractor from complying with the plans and specifications in all respects. The Contractor shall use only the approved methods and procedures during construction. If the Contractor desires to change any approved procedures, a written approval of the new procedures by — will be required.

2.2 Site Preparations

a. Clearing and Grubbing

The Contractor shall accept the site in the condition at the time the Contract Agreement is executed. All brush, roots, vegetable matter, large rock, and debris shall be removed from the site of the work within the limits shown on the plans.

All vegetation shall be removed from the land by dozing or power raking until the natural earth is cleaned of all vegetation. This vegetation shall be disposed in the designated areas or shall be burned.

All debris resulting from the clearing operations shall be piled and burned within the clearing limits or placed in the disposal area at such times, and in such a manner, as not to cause damage to public or private property. Remains of incompletely burned material and ash shall be disposed in the disposal area. The Contractor shall secure a burning permit if required.

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*Only selected sections have been excerpted; identifying names have been omitted.

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b. **Well Abandonment**

Monitoring wells located within the project area are to be sealed and abandoned.— shall locate and mark all well sites in the field. The wells will be sealed by — using approved methods to a point aproximately five (5) feet below the bottom of the clay seal layer.

The Contractor shall excavate around any existing well casings and cut off the casing five (5) feet below the bottom of the clay seal layer. The resulting excavation, and any associated disturbed soils, shall be backfilled and compacted up to the elevation of the bottom of the clay sal layer, as specified in Section 2.12b.

2.3 Borrow Pit Excavation

a. **Construction Material Sources**

All materials used to construct the embankment, clay seal and riprap elements of the project shall be obtained from specified borrow areas. Native soils for embankment and protective blankets will be obtained from the borrow area within the impoundment area of the Boric Acid Plant Tailings Disposal Pond or the borrow area located north of the construction site (Area B). Material for the clay seal has been stockpiled southeast of the circular pond (Area E). Lake clay is stockpiled about four (4) miles south of the — facility (Area C). Gangue materials for construction of the sacrifical layer beneath the pond bottom seal area is available from the west side of Pond 1 (Area D). A Riprap borrow pit (Area A) is located immediately north of the west end of existing Pond 5.

b. **Development of Borrow Areas**

The Contractor has sole responsibility to excavate materials from any and all borrow areas in such a manner as to produce a regular surface upon completion of the project. The final lines and grades shall be congruent with the surrounding natural terrain and shall not impede nor accelerate natural surface drainage. The location and limits of the borrow areas are shown on the plans.

c. **Borrow Area "A" - Riprap**

Rock protection for the interior slopes shall be excavated from Borrow Area "A" shown on the plans. It shall be removed from as small an area as practicable to preserve as much of the natural terrain as possible. Operations shall leave uniform slopes. No excavation will be permitted below elevation 2450.

d. **Borrow Area "B" - Native Soils**

The project is designed so that most - or all - of the material used to construct the embankment and protective blanket will be

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3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

obtained from the excavation within the pond basin. If the basin excavation is insufficient to complete the embankment and protective blanket to the lines and grades shown on the plans, the required material shall be excavated from Borrow Area "B" shown on the plans. All slopes resulting from borrow excavation shall be smooth, uniform, and not steeper than 10 horizontal to 1 vertical. Any waste or over-sized material segregated from the native soil fill material shall be placed in the disposal area shown on the plans.

e. Borrow Area "C" - Rogers Lake Clay

Material for construction of the embankment seal shall be excavated from Borrow Area "C" shown on the plans. All material shall be excavated, loaded, and transported from this Borrow Area in a regular fashion leaving a smooth, uniform surface. All slopes resulting from the borrow excavation shall be no steeper than 3 horizontal to 1 vertical, and no closed depressions shall be allowed to remain.

f. Borrow Area "D" - Gangue Material

Material for the sacrificial layer beneath the bottom seal shall be obtained from the west side of Pond 1 above elevation 2438. All matrial obtained from this Borrow Area shall be excavated to result in uniform finished surfaces, none of which shall have a slope gradient greater than 1.5:1, and which do not interfere with access to either Pond 1 or completed Pond 6. —— may reject some material from this Borrow Area if - in their opinion - it is unsuitable for use in the sacrificial layer. Also, —— may elect to deliver gangue to Borrow Area "D" in lieu of excavating portions of the Pond 1 embankment.

g. Borrow Area "E" - Clay Seal

A clayey shale derived from the mining operations has been stockpiled in Borrow Area "E". This material shall be used to manufacture fill for the pond bottom clay seal. Over-size, waste or otherwise unsuitable material for this operation shall be placed in the disposal area shown on the plans.

2.4 Foundation Preparations

An embankment foundation consisting of at least two (2) feet of compacted fill shall be provided prior to placement of embankment fill. This foundation may be established by either: (1) Excavating to a depth of eighteen (18) inches and processing the resulting surface by adding enough water to produce a uniform optimum moisture content in the upper six (6) inches and compacting in-place, or (2) excavating the entire two (2) feet of soil and watering the resultant surface prior to replacement. After the foundation excavation has been completed, but prior to any surface preparation, the finished surface will be inspected by —— and the representative from the State. Inspection by State may in some cases reuqire a delay of a few days due to their scheduling. The Contractor shall not proceed with surface preparation or embankment fill until approved in writing by —.

All removed soil shall be replaced in thin lifts, with maximum uncompacted thickness of eight (8) inches, brought to optimum moisture content, and compacted. The minimum compaction standard is 90 percent of maximum density, as determined by ASTM Test Designation D 1557-70.

2.5 Embankment Fill Construction

a. Embankment Materials

Approved granular alluvial soils excavated from the pond basin or the designated borrow area are to be used for construction of the embankment. Rock up to four (4) inches in maximum diameter can be incorporated in the fill by normal procedures providing the volume of rock two (2) to four (4) inches in diameter does not exceed 20 percent of the total volume at any location.

b. Placement of Embankment of Material

The fill shall be placed on prepared and approved ground surface, spread in thin horizontal lifts with a maximum uncompacted thickness of eight (8) inches, watered to specified moisture content, and compacted to 90 percent of maximum density. Compaction shall be accomplished by the necessary number of complete passes of the equipment to compact all portions of the embankment to a minimum relative compaction of 90 percent of maximum density, as determined by ASTM Test Method D 1557-70. embankment materials that are compacted to less than 90 percent of maximum density shall be rejected and removed or reworked and recompacted at the direction of —.

Benching shall be required where the embankment soils are to be placed abutting the existing west slope of Pond 1. Horizontal benches shall be cut into the slope of Pond 1 during the placement and compaction of each fill lift to bond the new fill to the existing slope. The benching and reprocessing shall be sufficient in extent to incorporate the exterior four (4) feet, measured horizontally, of the existing Pond 1 slope into the new embankment fill. Greater benching and reprocessing of the Pond 1 embankment may be required at the sole discretion of — where existing materials are determined to be unsatisfactory. Any additional excavation and backfill of the existing embankment, which is ordered in writing by —, shall be measured and paid as Auxiliary Fill, as specified in Section 2.12.

Finished embankment slopes shall be compacted to the face of their surface. Compaction shall be achieved by (1) overfilling the slope and cutting back to properly compacted fill, of (2) by compacting the slope face after the embankment reaches full height. Compaction for the second option shall be obtained by rolling the slope parallel to the surface with a sheepfoot tamper on a cable.

Before placement of the clay seal on the interior slope, the surface shall be smoothed and compacted parallel to the slope., The resulting prepared surface shall be approved by — prior to placement of the clay seal. The finished embankment surface shall be constructed to within plus or minus 0.2 feet of the lines and grades shown on the plans.

c. Embankment Moisture Control

The embankment material shall be placed at a moisture content controlled between 4 percent on the wet side and 0 percent on the dry side of optimum. Primary moisture conditioning shall be done in the basin excavation and borrow area with final adjustment to specified moisture content made on the embankment. The minimum moisture content of fill material transported from the basin excavation and borrow area shall be optimum. Moisture conditioning in the basin excavation and borrow area shall include ripping, discing, watering, and aerating soils having moisture contents less or greater than specified.

Embankment fill soils containing excess moisture shall be removed or shall be dried to proper moisture by scarifying and aerating and/or blending with a drier material before compaction.

Borate water from the nearby solar evaporation ponds will be used for processing embankment soils, except as specified in Section 2.16a. The Contractor shall provide the necessary piping, pumping and/or transport of this water to the job site as specified in Section 2.16.

Water trucks used for moisture conditioning shall be sufficient in number and total capacity so as never to delay embankment production. All water trucks used on the embankment shall be equipped with pressurized distributors bars having a length approximately equal to the width of a dumped scraper-width of earth. Gravity or splash distribution wil not be permitted. Pumps and water trucks with brass valves or piping should not be used due to corrosion by borate water, as noted in Section 2.16.

2.6 Sacrificial Layer Construction

a. Sacrificial Layer Materials

The sacrificial layer shall be constructed of gangue soils obtained from Borrow Area "D". The compacted sacrificial layer shall consist of approved materials containing no particles greater than two (2) inches in maximum dimension. Oversized or unsuitable materials shall be segregated at the borrow area.

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b. Compaction of the Sacrificial Layer

The sacrificial layer shall be placed directly on the approved pond bottom excavation to provide a smooth uniform finished surface and a minimum compacted thickness of 0.3-foot. Gangue soils shall be watered to between 110 percent and 115 percent of optimum moisture content before compaction, as determined by the standard ASTM Test Method D 698-70. Compaction shall be achieved by a method that precludes contamination of the gangue with underlying alluvial soils. The sacrificial layer shall be compacted to a minimum 95 percent of maximum density.

2.7 Clay Seal Construction

a. Bottom Seal Materials

The pond bottom seal shall be constructed of clean clay shale material taken from the dump stockpile in Borrow Area "E", which has been passed through a screen with four (4) inch openings. Selectivity will be required during excavation of clay shale from the designated stockpile for use in the bottom seal. Unsuitable material containing a preponderance of borate minerals or excessive sand content may be rejected by —, and will be removed from the stockpile. Unsuitable material and oversized material shall be transported by the Contractor to the designated disposal area.

b. Embankment Seal Materials

The interior embankment seal layer shall be constructed of — Lake Clay obtained form the stockpile located at Borrow Area "C". Excavation, loading, and haulage of the — Lake Clay shall be performed as specified in Section 2.3 and in accordance with applicable vehicle codes.

The borrow area shall first be stripped of any unsuitable surface materials to ensure procurement of clean, uncontaminated clay materials.

Excavation and loading of clay stockpile materials shall be performed so as to preclude contamination by unsuitable materials.

After procurement of adequate quantities to complete the interior embankment seal, the clay stockpiles shall be smoothed and contoured to produce a uniform finished surface. Care shall be taken to eliminate closed depressions and/or overly steep slopes so as to provide positive surface drainage.

c. Conditioning and Processing Clay Seal Materials

The clay seal materials processing and conditioning surface shall consist of either the completed and accepted sacrificial layer or the already completed and accepted seal. The size of the processing

BEGIN LAST LINE OF TEXT
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3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

area shall be sufficient to satisfy the Contractor's operating procedure. Approved clay seal materials will be spread uniformly on the processing surface. Conditioning of the clay seal layer materials shall consist of one complete pass with a rotary mixer, and watering to bring the moisture content of all material in the lift to 110-115 percent of optimum. Following a minimum 20-hour delay, an additional pass will be made with the rotary mixer adding sufficient water to bring the moisture content to 120 to 125 percent of optimum. The second pass will be made in the same direction as the first with an offset of exactly one-half the equipment width on each row. After the second mixing, the clay seal materials will be allowed to remain in-place or be stockpiled for a minimum curing period of twenty (20) days. During the curing period moisture in the processed materials shall be maintained by covering or periodically spraying the surface with water.

Fresh water shall be used for processing the clay seal materials. Water will be provided by — at a source designated by —. Transport, piping and storage of fresh water for use in processing the clay seal materials shall be provided by the Contractor as specified in Section 2.16.

d. Placement of Clay Seal

The clay fill materials for the bottom seal shall be spread and compacted systematically in a minimum of three (3) lifts of equal thickness. The — Lake clay material for the embankment seal shall be spread and compacted in a minimum of two (2) lifts of equal thickness. Compaction shall be accomplished by the necessary number of complete passes of the compacting equipment to compact all portions of each lift to a minimum relative compaction of 95 percent of the maximum density, as determined by ASTM Test Designation D 698-70. The clay seal materials shall have a minimum moisture content of 110 percent of optimum moisture at the time of compaction. The surface of the final lift shall be finally compacted with equipment that will produce a smooth, uniform finished surface. The embankment clay seal shall be placed and compacted in lifts parallel to the slope of the interior embankment. The moisture in the clay materials shall be maintained by the Contractor until the clay seal is covered by the protective blanket or embankment fill.

An approach pad of gangue soils shall be placed wherever access is required to the clay seal. The pad or pads shall be of sufficient size to remove sand from the wheels or tracks of vehicles and other equipment prior to passing onto the clay seal processing or placement areas. Care shall be taken to prevent alluvial soils or other foreign materials from contaminating areas where the clay seal materials are being processed, placed or compacted.

2.8 Protective Blanket Construction

a. Protective Blanket Material

The protective blanket shall consist of approved granular alluvial soils from the basin excavation or Borrow Area "B". The material shall contain no particles with a maximum dimension greater than four (4) inches.

b. Compaction of Protective Blanket

The protective blanket shall be compacted to at least 83 percent of maximum density, as determined by ASTM Test Method D 1557-70. The protective blanket shall have a final compacted thickness of no less than 0.8-feet.

2.9 Riprap Slope Protection

a. Riprap Material

The Contractor shall furnish and install riprap cover to protect the interior embankment slopes, as shown on the plans. Riprap material shall be obtained by excavating and processing rock from Borrow Area "A".

Riprap shall be excavated from the designated quarry location after stripping the existing surface of residual soil and rock. Riprap will not be subject to size restrictions.

b. Riprap Placement

Riprap shall be placed in a single uniform layer by dumping and spreading. A method of dumping and spreading which does not concentrate the larger particle sizes in the lower portion of the slope shall be used. After the material is spread, it shall be consolidated and bedded by track-rolling with a bulldozer.

2.10 Subdrain System Construction

a. General

The pond subdrains consist of two independent monitor systems constructed beneath the clay seal layer. The subdrains have a gravel collector and transmission section overlying a continuous polyethylene plastic sheet, all of which are placed in a graded V-ditch cut to the lines and grades shown on the plans. Any waters conveyed by the gravel section will be collected by perforated plastic drainage pipe embedded in the discharge terminus of the gravel section and directed to an accessible sump via non-perforated plastic pipe. A concrete cut-off wall shall be used to seal the discharge terminus of the gravel section, plastic film and joint between the perforated and non-perforated pipe.

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b. Subdrain Filter Material

The subdrain section shall consist of approved imported filter material having a minimum coefficient of permeability of 100 feet per day. The filter material around the perforated pipe shall have a grain size gradation which protects against migration of fines into the pipe, and shall be approved by — at the source prior to placement.

c. Polyethylene Plastic Sheeting

The polyethylene plastic sheet that seals the bottom of the subdrain ditch shall consist of 96 inches wide by 0.01-inch thick (10 mil) film fabricated and spooled in unfolded continuous rolls containing approximately 250 linear feet of material.

d. Plastic Pipe

The plastic piping shall be minimum 3-inches in outside diameter and have a minimum crush strength of 1250 pounds per linear foot according to ASTM Test Method D 3298-74. The perforated piping shall be provided with two (2) rows of maximum one-quarter inch diameter holes spaced a minimum of six (6) inches on center along the length of pipe. The rows shall be spaced approximately 90 degrees apart, as measured on the circumference of the pipe. Both the perforated and non-perforated piping shall be capable of being joined by solvent welding using compatible slip joint couplings and the appropriate plastic pipe cement. Pipe and fittings shall be as manufactured by Capco, Inc. (polystyrene Hi-Pac 125) or approved equal.

e. Subdrain Sump

The subdrain sump located at the discharge terminus of the non-perforated plastic pipe shall consist of 48-inch diameter, 16 gauge, corrugatged, galvanized steel pipe set in a poured concrete base. The sump shall be provided with a rain-tight metal access lid and ladder rungs, as shown on the plans.

f. Subdrain Grading

The subdrain V-ditch shall be cut to the lines and grades shown on the plans, plus or minus 0.1-foot. Each subdrain V-ditch shall be excavated, and approved by — prior to placing any subdrain materials. The excavation of the subdrain trenches shall include sufficient space along side of the finished V-ditch for access of equipment required to complete the specified subdrain section. Final cuts to finish grade shall be made with a motor grader to assure a smooth uniform surface. After the finish grading, and before the plastic sheet is placed, the V-ditch shall be hand cleaned and/or raked to remove any loose materials, pebbles, or other objects that might puncture the plastic sheet, and be objects that might puncture the plastic sheet, and be approved by —.

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3/8"

PAGE NUMBER

EPA-287 (Cin.) (4-76)

g. Placement of the Plastic Sheet

The plastic sheet shall be unrolled over the ditch and held in place against shifting by filter material. Butt joints between rolls shall be overlapped two (2) feet on either side of the joint with the end of the downstream roll being placed beneath the upstream roll. Where two V-ditches join at a "Y" the plastic sheeting entering from the side shall be placed on top of and extend to at least the invert of the main ditch sheet. All plastic sheet joints shall be heat-sealed to produce a uniform, water-tight, fusion weld at least one inch wide. No filter gravel shall be placed within five (5) feet either side of a joint prior to sealing. Joint details shall be as shown on the plans.

h. Placemenmt of the Subdran Filter Material

The filter material shall be placed on the plastic sheeting to provide the required section, as shown on the plans. The material shall be deposited in such a fashion as to not damage the underlying plastic sheet. Any damaged sheeting shall be replaced at the expense of the Contractor. The upper surface of the filter material shall be smoothed and approved by — prior to back-filling.

i. Subdrain Trench Backfill Compaction

The completed and approved subdrain section shall be covered with granular soils and compacted according to the specifications of Section 2.12b, and the subdrain excavations backfilled to the base of the seal layer.

j. Sump Construction

The subdrain discharge sumps shall be constructed to the dimensions shown on the plans. All earth backfills shall conform to specifications of Section 2.12b.

2.11 Channel Control Dike Construction

a. Channel Excavation and Dike Construction

The channel control dike shall be excavated to the lines and grades shown on the plans and staked in the field. Material resulting from the channel excavation shall be used to construct the dikes.

b. Compaction of Channel Control Dike

The channel control dikes shall be processed and compacted, as specified in Section 2.12b.

TYPING GUIDE SHEET

2.12 Auxiliary Fill

a. Auxiliary Fill Material

The auxiliary plans, required in writing by —, shall include - but not be limited to - well abandonment backfill, additional foundation over-excavation and special ramps required by —.

b. Compaction of Auxiliary Fill

Auxliary fill shall be placed in thin lifts having an uncompacted thickness not exceeding eight (8) inches. It shall be placed, processed, and compacted in a systematic way. Where fill is placed on the natural grade, the existing surface shall be watered and compacted to a depth of six (6) inches. If auxiliary fill is placed adjacent to the pond embankment, the underlying material shall be processed as specified under foundation preparation (Section 2.3). The auxiliary fill shall be brought to optimum moisture content and compacted to a minimum of 90 percent of maximum density, as determined by ASTM Test Method D 1557-70.

2.13 Accessory Clay Seal

The accessory clay seal consists of any clay seal fill not shown on the plans, but requested in writing by —. It shall include, but not be limited to, any additional seal layer thickness required by —.

a. Accessory Clay Seal Material

The accessory clay seal materials shall be as specified in Section 2.7a.

b. Conditioning and Processing of Accessory Clay Seal Materials

The conditioning and processing of accessory clay seal materials shall be as specified in Section 2.7c.

c. Placement of Accessory Clay Seal Materials

The accessory clay seal materials shall be spread, processed, and compacted in lifts not exceeding six (6) inches in uncompacted thickness. Moisture content, compaction, finishing and maintenance shall be as specified in Section 2.7d.

2.14 Compaction Equipment

It is not the intent of these specifications to restrict brands or mandate types of compaction equipment, as the end result is paramount. Accordingly, if it is desirable to use a type of equipment larger or more efficient than that designated, a change should be proposed to __ for

EPA-287 (Cin.)
(4-76)

approval. The efficiency, the required number of passes, and the judgment of — relative to the approval of the proposed alternative piece of equipment will be based on demonstrated test results on a test fill.

The clay seal shall be compacted by rolling with a bulldozer, rubber-tired equipment of a tamping roller. If either a tamping roller or tracked equipment is used to compact the clay seal material, the final surface shall be finished by rolling with rubber-tired equipment or equivalent to produce a smooth uniform surface. Rollers shall be equipped with cleaning fingers, suitable to prevent clogging of the material between the feet.

The embankment fill, other than the clay seal, may be compacted by a Wagner-type compactor, a sheepsfoot tamping roller or by heavy rubber-tired equipment at the option of the Contractor. If rubber-tired equipment is used for compaction, the specific equipment to be used shall be approved by —.

2.15 Inspection and Control of Earthwork

— shall inspect and approve all original ground cleanup, and processing before fill placement. A field laboratory will be maintained by — for the purpose of making compaction tests during fill placement. A minimum of one relative compaction test will be made for each two thousand (2000) cubic yhards of fill. These tests will be used as a guide to determine whether or not fill is being satisfactorily compacted. The Contractor shall coordinate his work so that the required tests can be taken.

Control of the existing ground preparation and the control of all fill will be by the end result method. Relative compaction tests shall be taken by — during all grading operations. Results of the tests will determine if the fill has been properly placed.

Permeability tests will be conducted by — during construction on undisturbed samples of the compacted clay seal taken from the completed seal layer. These tests will confirm that the design permeability is being obtained in the field. The compacted thickness of the clay seal shall be measured and approved by —.

Inspection, testing, and approval by —, their representatives or governmental agencies may cause temporary delays in the work. No protective blanket or cover materials shall be placed on the completed seal layers until permeability testing is completed for a specific area, and the seal layer accepted. A two (2) week delay for permeability testing and final approval should be anticipated by the Contractor. During this period the specified seal moisture content shall be maintained by periodic watering. The Contractor shall organize his work so that these delays shall not cause interference with the general progress of construction.